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FUNDAMENTALS OF AVIATION MEDICINE

by A. A. Lavnikov

"Military" Press, Moscow, 1971

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JULY 1972

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Translation of: "Osnovy Aviatsionnoy Meditsiny."
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ANNOTATION

The book traces the principal information on the historical development of aviation medicine in our country, describes the structure of the Earth's atmosphere, gives a brief survey of human anatomy and physiology, and also discusses the effect of various flight factors on man. It also specifies the physiological and hygienic requirements for cabins of modern aircraft and the oxygen-respiration apparatus, discussing the influence of particular aspects of flights under difficult meteorological conditions and at night on the pilot's body. The problems involved in feeding a flight crew are discussed at the end. /2*

The book is intended for students at aviation academies, those studying at flight schools and pilots in the air force. It may also be valuable to flight surgeons, the engineering-technical crews of the air force and other fields of aviation, students at medical institutes, design organizations, dealing with aviation technology, and everyone who is interested in aviation and aviation medicine.

*Numbers in the margin indicate pagination in the original foreign text.

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This book is dedicated to the people who work in a heroic profession — Soviet pilots.

.... Author

FOREWORD

Aviation medicine is a special branch of general medicine, firmly linked /3 to the development of aviation. The scope of the scientific and practical problems solved by this branch of medicine is constantly expanding.

Thanks to the tireless efforts of the Communist Party and our government, the Soviet Union has the most advanced aviation technology in the world. Our military aviation consists of jet aircraft, supersonic planes, rocket-carrying and all-weather planes.

Modern fighter planes have flight speeds far in excess of the speed of sound, and their maximum flight altitudes exceed 30 km. It was in our country that the first supersonic passenger aircraft, the TU-144, rose into the air in December, 1968. Its cruising flight speed is 2500 km/hr. Modern transport jet planes have cruising speeds of 900 to 1000 km/hr.

Aircraft capable of vertical takeoff and landing have been designed and built in many countries, as well as aircraft with wing geometries which can be altered in flight. Soviet planes of this type were displayed at the celebration of Air Force Day at Domodedovo Airport near Moscow (in 1967).

Further improvement in aircraft will involve increasing the altitude, speed, range and duration of flight. The development of aviation technology also complicates the working conditions of those persons who are involved in flying them. Flights aboard modern aircraft, especially under difficult meteorological conditions and especially under combat conditions, place considerable stress on the mental and physical powers of the pilot. Therefore, the flight crew must be in good health, possess considerable working ability and endurance, rapid perception and reaction, emotional stability and strength of will. Special demands on the physical and neuropsychological state of the flight crew are determined by the specific operational conditions under the strong influence of continuous factors of the external environment.

These factors include the following: acceleration, changes in atmospheric /4 pressure and air temperature, reduced partial pressure of oxygen in the inspired air, noise and vibration, long periods of time spent in a fixed position and high-altitude equipment. All of these factors largely determine the problems of aviation medicine and the trend of its activity, involved in preserving the health, working ability and safety of the flights made by the crew.

Modern aviation medicine deals with the following principal problems:

It provides a scientific solution for the physiological and hygienic problems affecting flight of aircraft of different types in order to insure the most favorable working conditions for the flight crews;

Together with the engineers, it works out effective means of rescue in the event that dangerous situations arise in the air;

It insures the medical selection in aviation of contingents which correspond to required health standards and works out methods of selection;

It performs the study of professional diseases of individuals on flight crews and attends to their prevention.

The principal branches of aviation medicine are physiology, hygiene in flight operations, aviation psychology and medical-pilot expertise.

A strong indication of how various factors involved in flight influence the human organism and the necessary recommendations worked out by aviation medicine guarantee preserving high combat skill of the pilots and increasing the safety of flights. Therefore, the flight crew must be familiar with the basic outlines of aviation medicine.

CHAPTER I

THE HISTORY OF AVIATION MEDICINE IN OUR COUNTRY

The birth of aviation medicine took place during the construction of the first flying machines. In the development of aeronautics and aviation, the problem of the effect of various flight factors on the human organism was studied continuously (low temperatures, pressure decreases, lack of oxygen, etc.). Each new achievement in aeronautics and aviation posed new problems for medicine, making it necessary to find means and methods of eliminating or relieving the influence of these factors on the physical state and health of the people. /5

In Russia, the study of the influence of flight conditions on the human organism was begun by Academician Ya. D. Zakharov. In accordance with the instructions of the Russian Academy of Sciences, he made a flight in a balloon on 30 June 1804. The flight lasted more than three hours, during which time the balloon rose to an altitude of a little more than 2000 m. During the flight, Zakharov made observations of the weather as well as changes in hearing, vision, and respiration.

The first Russian doctor to make flights in a balloon was staff doctor Kashinskoy of the Lefort Hospital[1]. He built the balloon himself, and ascended in it from the Neskuchnvy Gardens in Moscow on 24 September and 1 October 1805.

(1) Moskovskiye Vedomosti, 1805, pp. 2011, 2019, 2049, 2083.

Dr. Kashinskoy undoubtedly was aware of the cognitive value of the observations made by Ya. D. Zakharov during his flight and performed them himself. The data which he obtained were studied and evaluated by the medical community. It is claimed that the experience of Kashinskoy's flights later served as a basis for the participation of physicians in solving the problem of checking out pilots for flight.

The talented physicist, M. A. Rykachev, who began to make balloon flights beginning in 1868, along with meteorological observations, conducted tests of visibility and audibility in flight and also observed his own sensations. Rykachev was the first to enumerate the qualities which must be possessed by a flier: "Controlling the balloon calls for the same qualities required of a sailor: rapidity of comprehension, self-control, retention of presence of mind, circumspection, attentiveness, nimbleness."

Many of the experiments performed and statements made by D. I. Mendeleyev are of considerable importance for aviation medicine in our country. Thus, in 1875, he was the first in the world to point out the necessity for having a hermetically sealed cabin when making flights into the higher layers of the atmosphere and worked out a system for a balloon with such a cabin. He also suggested compressing gas into steel cylinders, in which it could be stored and carried around. This method is used even today in the provision of oxygen supplies for flights. Mendeleyev also wrote about the need for a comfortable motorized apparatus available to all. There is a basis for believing that it was under the influence of his ideas concerning "comfort" that the Russian airplane "Il'ya Muromets" (1914) became the first in the history of aviation to have elementary hygenic comfort such as was not available on any foreign aircraft at the time. On 7 August 1887, Mendeleyev made a free flight in a balloon.

Other Russian scientists also made flights in balloons. Each such flight enriched science with new discoveries. It was not only the direct study of man under flight conditions which was important for the development of aviation medicine, but also the tests which were conducted in the related branches of medicine long before the construction of the airplane and even the balloon.

In the second half of the last century, when the idea of the conquest of the air became most popular, Russian doctors carried out a number of theoretical studies which had an important influence on the development of aviation madicine. Thus, for example, Doctor A. Katolinskiy performed several physiological and clinical experiments in 1862 involving the study of the effect of /7
rarefied and "compressed" air on the human organism and provided literature on this problem which was extensive for the time. The outlines of a "pneumotic chamber", the prototype of the barochamber which was included in his work, is of considerable interest. In addition, further studies in this direction were conducted by the Russian doctors, Smirnov (1866), P. Kochanovskiy (1875) and L. N. Simonov (1876).

In 1873, the famous Russian traveller N. M. Przheval'skiy expressed the opinion that the cause of altitude sickness which develops during high mountain climbing is oxygen starvation.

In 1875, Dr. N. Stroganov, studying animals which had been placed in a closed space, worked on the problem of respiration and circulation with progressively decreasing oxygen pressure.

The experiments of M. Zhirmunskiy are of particular interest; their results were published by him initially in an article (1877) and then in his dissertation "The Influence of Rarefied Air on the Human Organism".

However, the theoretical foundation of aviation medicine lies not only in these works, but also largely on the classical works of I. P. Pavlov on the physiology of circulation (1874) and I. M. Sechenov on blood gases (1857).

In 1859, Sechenov was the first to determine the composition and the content of gases in the blood and in the alveolar air as a function of the amount of oxygen in the inspired air. In addition, he drew a number of conclusions regarding the activity of various portions of the central nervous system under conditions of oxygen starvation. By using simple calculations, he was the first to show that the leading factor in difficulties which arise in the organism during ascent into rarefied atmospheres is the decrease in the partial pressure of oxygen in the alveolar air. Somewhat later, in 1880, he showed that respiration becomes impossible if the partial pressure of oxygen in the alveolar air drops below 14 mm of mercury.

The French physiologist, Paul Behr, determined experimentally that the /8
principal cause of mountain and altitude sickness is the decrease in the partial pressure of oxygen in the surrounding atmosphere, and that the additional inspiration of oxygen under conditions of a rarefied atmosphere will completely do away with its unfavorable influence. But he failed to study the composition of alveolar air in the lungs at all.

Physiologist V. V. Pashutin continued the work of I. M. Sechenov on a problem that is of great importance to aviation medicine — the respiratory function of the blood. In 1881, he was the first in Russia to carry out a number of experiments involving the study of the influence of centrifugal forces on blood circulation. Similar studies were conducted by N. O. Tsybul'skiy (1879 - 1885), working in the laboratory of I. R. Tarkhanov.

The founder of cosmonautics, K. E. Tsiolkovskiy, performed experiments in 1879 - 1878 which were intended to solve a number of problems related to the influence of acceleration on living organisms.

The work performed by the outstanding scientist V. I. Voyachek is fundamental to the study of the influence of accelerations on the vestibular apparatus in man. He developed a method of studying the vestibular apparatus (1909 - 1910).

Hence, the first experiments involving the study of the influence of accelerations on the animal and human organism in Russian medicine were performed long before the birth of aviation.

The work of P. M. Al'bitskiy is especially important for aviation medicine; in 1880 he was the first to work on a study of the influence of prolonged oxygen insufficiency (up to several days) on the organism.

Doctor V. I. Grebenshchikov correlated the experience of medical flight safety in a balloon, which had been accumulated by the end of the last century, and presented his findings at a session of the aeronautical branch of the Russian Technical Society (1891).

The first medical worker to carry out flights in a joint aeronautical organization was the medical assistant Ivan Perfil'yev (1886).

In August 1887, the Main Military Engineering Administration, which supervised the Aeronautical Command (founded in 1885, and located at Volkov Field in St. Petersburg) approached the Main Military Medical Command with a request to name a flight doctor to protect flights. Beginning on 17 September 1887, these /9
responsibilities fell to the former doctor of the Jaeger Regiment, Karpyshev, who may therefore be considered the first Russian aviation doctor.

In 1897, at the Instruction-Aeronautical Park, military doctors, S. P. Munt was the first in the world to begin physiological and psychological tests of aeronauts in flight using a specially equipped balloon. These experiments were very important for the development of aviation medicine.

An important role in the solution of problems of aviation medicine was also played by clinical studies on the influence of high-altitude conditions on the human organism.

The most interesting experiments in this area are the results of the prolonged observations made by the young physician of the Second Turkestan Battalion, N. N. Tret'yakov, (from 1892 to 1894), on the conditions of a group of subjects (110 persons) living at a height of 3500 m.

In addition, important information for aviation medicine regarding the influence on the human organism of rarefied air was obtained in Soviet times (1930's) in a number of complex Elbrus and Pamir expeditions organized by the Academy of Sciences of the USSR, the S. M. Kirov Military-Medical Academy, the All-Union Institute of Experimental Medicine and the Institute of Nutrition as well as other institutes. The results of these experiments, published in the work of G. Ye. Vladimirov, G. G. Gazenko, A. P. Zhukov, A. N. Krestovnikov, N. N. Sirotinin and other Soviet scientists, supplement the data obtained under conditions of laboratory (in barochambers) and natural (in-flight) experiments.

The official date of the start of Russian aviation medicine may be considered to be 14 July 1909, when the council of the All-Russian Aeroclub decided on a compulsory medical examination of all pilots.

In 1911, the first expert order for the military department, No. 481, was issued; it established the annual re-examination of the state of health of pilots on special commissions and listed the diseases and physical deficiencies which would preclude service as a pilot.

It was approximately at this time (1910) that very timely experiments in /10
the field of aviation medicine were performed. These include the work of V. N. Okunev on the influence of flight on the organ of hearing and those of S. Gruzon on the physiological reactions to height, etc.

Russian aviation medicine entered World War I with considerable experience in the medical safety of flights and the development of medical and flight expertise. However, creative medical thought was severely retarded at the beginning of the war as far as its development was concerned, primarily due to a lack of specialists — aviation physicians. From 1914 to 1918, only three works were published which dealt with pilot activity (E. I. Dombrovskiy and N. Kostyamin, 1915, A. N. Sokolov, 1917).

After World War I, special institutes and laboratories of aviation medicine were founded in many countries, and the leading physiologists, hygienists, and psychologists worked in them.

In our country, aviation medicine began to develop rapidly only during the years of Soviet power. As early as the end of 1917, a special commission to study the work of pilots was founded in St. Petersburg at the Military-Medical Society of the Military-Medical Academy (Chairman — psychiatrist and Professor V. P. Osipov). A prominent role in the development of aviation medicine was played by S. Ye. Mints (1889 - 1925). Working from 1919 to 1924 as the head doctor of the Moscow Aviation School, he studied the conditions of flight duration and carried on active scientific research work. In June of 1921, at the Fourth All-Russian Congress of Air Travel, S. Ye. Mints, giving a paper on the preservation of the working ability and health of the pilots, proposed the establishment of psychotechnical laboratories in flight schools. The problems they dealt with included the study of working conditions and the individual qualities of pilots.

In accordance with the proposal of S. Ye. Mints, the orders of the Revolutionary Military Soviet Numbers 837 and 874 in 1924 established the Central Psychophysiological Laboratory for the Study of Military-Air Service /11
(on the basis of the school laboratory of Mints, which was already at work). Its head was N. M. Dobrotvorskiy, while his assistant and the head of the medical-pilot commission was S. Ye. Mints.

It was in this laboratory that the outstanding Soviet aviation physicians V. V. Andreyev, A. V. Lebedinskiy, A. P. Apollonov, Yu. A. Vasil'yev, P. I. Yegorov, N. A. Vishnevskiy, G. G. Kulikovskiy, V. G. Mirolyubov, I. K. Sobennikov, V. V. Strel'tsov and others began their activity.

The collective of workers at the laboratory ceased to apply the psychotechnical methods introduced by S. Ye. Mints for selection of candidates for flight schools and was occupied with the study of the functions of analyzers (sense organs) which play an important role in the pilot's profession. At the same time, the laboratory studied the changes in the cardiovascular and respiratory systems in pilots and phenomena of fatigue, developed proposals for modernizing flight suits and the pilot's working area in the aircraft, and also studied the importance of the personal factor in aviation accidents. An important influence on the development of Soviet aviation medicine was exerted by N. M. Dobrotvorskiy. His book entitled "Letnyy Trud" (Flight Labor), published in 1930, was the first Soviet handbook on aviation medicine. It is of interest to some degree even today. For several years, Dobrotvorskiy lectured on aviation medicine at the N. Ye. Zhukovskiy Military-Medical Academy. It is important to note that in those days not a single one of the military aviation teaching institutions in Europe or America was giving courses on aviation medicine.

In 1930, the Central Psychophysiological Laboratory was reorganized into the aviation sector of the Scientific Research Sanitary Institute of the Workers' and Peasants' Red Army. The head of the sector was the young energetic scientist, V. V. Strel'tsov (1931), who had done a great deal in the field of aviation medicine. Using as a basis the teachings of Academician I. P. Pavlov regarding higher nervous activity and the evolutionary-physiological concept of Academician L. A. Orbeli, he took a new approach to the solution of the most important problems in aviation medicine, especially the problem of high altitude training. /12

In 1930, extensive experimental work began to be performed in our country in the barochamber on the study of the influence of altitude on the human organism, the development of methods of barochamber training and testing of the first oxygen apparatus. In 1932, V. V. Strel'tsov was the first in the USSR to make an "ascent" in a barochamber to a height of 13,000 m. On his initiative, massive construction of barochambers for high altitude training of flight crews was organized. Physiological approbation and improvement of oxygen devices in the period from 1931 to 1954 was accomplished by a leading specialist in this field, A. P. Apollonov.

In conjunction with the rapid development of aviation in 1935, on the base of the aviation sector of the Scientific Research Sanitary Institute, the Scientific Research Sanitary Institute of the People's Commissariat of Defense was founded, which had shortly thereafter received the name of Academician I. P. Pavlov. This institute dealt with studying numerous problems of aviation physiology and hygiene. Outstanding specialists in the field of aviation medicine participated in the work of the institute: D. Ye. Rozenblyum, V. V. Strel'tsov, A. P. Popov, V. A. Spasskiy, V. G. Mirolyubov, P. K. Isakov, O. G. Gazenko, A. M. Genin, D. I. Ivanov, I. Ya. Borshchevskiy, V. V. Levashov and others.

The departments of the S. M. Kirov Military Medical Academy also dealt with problems of aviation medicine in the pre-war years; they were led by L. A. Orbeli, V. I. Voyachek, K. L. Khilov, M. P. Brestkin, G. Ye. Vladimirov, M. I. Arinkin, I. R. Petrov, P. I. Yegorov.

Thanks to the detailed studies carried out by Soviet physiologists, hygienists, psychologists and practical aviation doctors, our aviation medicine had acquired considerable scientific data prior to the outbreak of World War II and organized medical flight safety on this basis, keeping it at a high scientific level.

During World War II, appropriate scientific research sections dealt with a wide range of problems of aviation medicine which had mainly theoretical and especially practical significance.

During the postwar period, the scope of scientific studies in the field /13
of aviation medicine has undergone considerable expansion.

Aviation medicine, based on the achievements of Soviet materialist physiology and biology, is successfully solving problems which are posed by aviation science and practice.

CHAPTER II

A BRIEF DESCRIPTION OF THE ATMOSPHERE

Structure of the Atmosphere

The globe is surrounded by an envelope of air called the atmosphere. /14
Studies conducted with radiosondes, rockets, and artificial Earth satellites have provided extensive information regarding the changes in the composition of the atmosphere with altitude, its density, temperature, electrical state and so on. At the present time, the atmosphere is conditionally divided on the basis of the change in temperature with altitude into five principal layers (Figure 1): the troposphere, stratosphere, mesosphere, thermosphere and exosphere.

The troposphere is the lowest and densest layer of the Earth's atmosphere.
Its thickness is not the same over all parts of the globe: It is 10 to 12 /15
kilometers at middle latitudes, 7 to 10 km above the poles, and 16 - 18 km above the Equator.

The principal mass of the air and practically all of the water vapor is concentrated in the troposphere. A characteristic feature of the troposphere is the decrease of temperature and atmospheric moisture with altitude, as well as the presence of rising and descending currents and the condensation of water vapor. In this layer of atmosphere, clouds and fogs are formed, precipitation falls (rain, snow), thunderstorms develop, the humidity is constantly changing, as well as the pressure and temperature, i.e., all of the phenomena which govern the weather.

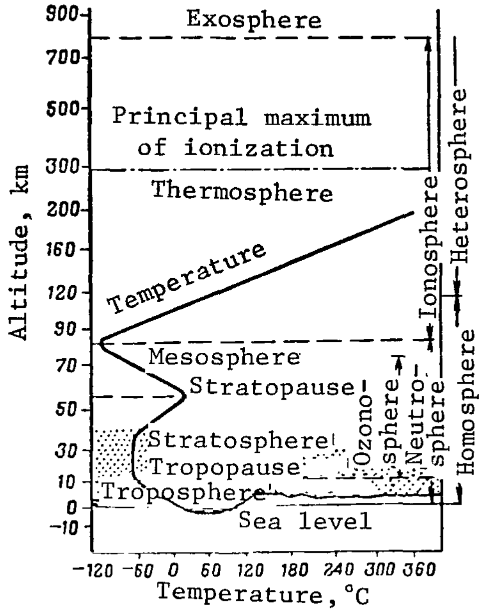

Figure 1. Diagram of vertical structure of atmosphere.

The conditional boundary between the troposphere and the stratosphere is assumed to be the altitude above sea level at which a further decrease in temperature ceases. There is an intermediate layer between them called the tropopause, from 1 to 3 km in thickness. In this layer, the temperature of the air may increase or remain constant. The height of the tropopause is not constant. It varies depending on the time of year; it is higher in summer than in winter. The diurnal variations in the height of the tropopause are also significant. In addition, the height of the tropopause is dependent on the nature of the developing atmospheric processes: above the areas with low air pressure (cyclones) the tropopause is lower, while above areas with high pressure (anticyclones) it is higher.

The stratosphere is the layer of the atmosphere which lies above the troposphere and extends up to an altitude of 50 to 60 km. The stratosphere is characterized by a considerable rarefaction of the air, negligible moisture, almost complete absence of clouds, a high level of ultraviolet radiation, absence of dust of terrestrial origin, constant direction of main air currents, and an attenuation of atmospheric turbulence. Sometimes nacreous clouds are observed here.

The temperature changes slightly in the stratosphere up to altitudes of 25 to 30 km, but then increases gradually. The principal reason for the temperature increase is the fact that ozone has its maximum concentration in the upper part of the stratosphere. In middle latitudes, the temperature at the upper limit of the stratosphere is equal to -11 to -12°C, on the average.

The mesosphere is the atmospheric layer which is located at altitudes from 50 to 60 to 80 to 90 km. In this layer, the temperature decreases with increasing altitude from values close to 0° C to -80 to -90° C. This is where argentous clouds are observed.

The mesosphere is separated from the stratosphere by an intermediate layer called the stratopause.

The thermosphere is the atmospheric layer which extends from an altitude of 80 to 90 km to approximately 800 km. In this layer, temperature increases rapidly with increasing altitude. Observations indicate that at 300 to 400 km it can reach 1,000° C and more[(2)]. Auroras are frequently observed in this layer. /16

The boundary between the mesosphere and the thermosphere is called the mesopause.

Above the thermosphere is the exosphere, or the sphere of scattering. In this layer, the gases are so rarified that their particles are located at great distances from one another. The rates of movement of gas molecules in the scattering sphere are so great that the molecules sometimes overcome the Earth's gravitation and fly out into interplanetary space. Thus, there is a leakage of gases into outer space which takes place very slowly but continuously. It is the particles of the light gases which are scattered most in this fashion — hydrogen, helium, neon. The exosphere does not have a definite upper limit, since it gradually merges with interplanetary space. On the basis of scientific data obtained in recent years, we can say roughly that it extends to an altitude of about 3,000 km.

[(2)]Due to the high rarefaction of the air, the temperature of the medium here is purely conditional and characterizes only the velocity of individual molecules.

The entire mass of atmospheric air is distributed as follows: approximately 80% is in the troposphere, about 20% in the stratosphere, no more than 0.3% in the mesosphere, and less than 0.05% in the thermosphere and exosphere.

On the basis of electrical properties, i.e., the distribution of electrically charged particles through the atmosphere (ions), we can divide the atmosphere into the neutrosphere and the ionosphere (Figure 1). Ionization takes place as the result of the action of solar and cosmic radiation on molecules and atoms of gases which make up the air. When the density of the air is still rather high, the collision of gas particles carrying positive and negative charges forms uncharged or neutral molecules and atoms. This pro- /17
cess takes place at altitudes up to 80 to 100 km. The layer of the atmosphere in which the neutral particles are formed is called the neutrosphere.

At altitudes above 100 km, where the air is highly rarefied, collisions of gas particles take place much more rarely, and many particles retain their charges. This area of the atmosphere is called the ionosphere. The principal feature of the ionosphere is the increased contact of ions and free electrons in the medium as well as the high electrical conductivity of the air in this layer. The principal ionization maximum is located at an altitude of approximately 300 km.

Composition of Atmospheric Air

Atmospheric air is a physical mixture of different gases. It contains the following: nitrogen (78.08% of the total volume), oxygen (20.95%), argon (0.93%), carbon dioxide (0.03%) hydrogen (0.005%), neon (0.0018%), helium (0.00015%), as well as traces of krypton and xenon. Thanks to the constant movement of the air, this gas composition is retained up to an altitude of approximately 110 km.

The layer of the atmosphere with a constant gas composition is called the homosphere. Above the homosphere, the gas molecules break down into atoms, and there is stratification of the gases under the influence of gravity. Here the air becomes a mixture of varying composition. This layer of the atmosphere is called the heterosphere.

There is also an ozonosphere, a layer of the atmosphere which is located at altitudes from 20 to 70 km and is rich in ozone.

It has been established in recent years that at altitudes from 100 to 200 km the ionosphere consists of ions of oxygen (O_2^+), nitrous oxide (NO^+), and atomic oxygen (O^+). Beginning at altitudes of 140 to 160 km, predomination of atomic oxygen ions begins, while above altitudes of 200 to 250 to 1,000 km the ionosphere consists almost completely of atomic oxygen (O^+). Beginning at a height of 500 km, insignificant amounts of ions of atomic nitrogen (N^+) are found in the ionosphere.

The air always contains moisture in the form of water vapor (about 1% by /18
volume). Depending on the climatic zone and the time of year, the amount of water vapor in the air can vary in volume from 0.01% to 4%. Water which is evaporated from the surface of the oceans, seas, rivers, lakes, and the soil enters the atmosphere. The atmosphere always contains more than 10,000 billion tons of water in the form of vapor. Condensation of water vapor leads to the formation of clouds and precipitation. Hence, there is a constant circulation of water going on in nature.

The amount of water vapor which determines the degree of humidity of the air depends primarily on the temperature of the air. Usually, the higher the air temperature under specific conditions, the greater the amount of water vapor which it can hold.

Such values as absolute and relative humidity are used to characterize the moisture of the air.

The absolute himidity of the air is the amount of water vapor (in grams) contained in one cubic meter of air. At a specific temperature, the air will contain only a certain amount of water vapor. Air with a maximum content of water vapor is called saturated. In the equatorial zone, absolute humidity reaches about 20 g/m^3; at middle latitudes in summer it reaches 5 to 7 g/m^3, while in winter during severe frosts it can be less than 1 g/m^3.

Relative humidity of the air is the ratio of the amount of water vapor in the air at a given moment to the maximum possible amount at that temperature. Relative humidity of the air is expressed in percent.

The amount of water vapor in the air decreases with altitude. Thus, at a height of 1.5 to 2 km, it is only half (and at 5 km — $1/10^{th}$) as much as at sea level. The relative humidity of the zone of cloud formation reaches 100%.

The principal mass of the water vapor is concentrated in the lowest layer of the atmosphere, whose thickness is 10 - 12 km.

Ozone is formed in the stratosphere as a result of disassociation of oxygen molecules under the influence of ultraviolet radiation from the Sun and cosmic rays. In the lower layers of the atmosphere, a small amount of ozone is formed during lightning discharges. Ozone is found in the atmosphere in a scattered state in a layer which extends approximately up to an altitude of /19
70 km. If all of the ozone contained in the atmosphere were concentrated (at a pressure of 760 mm Hg and a temperature of 0° C), a layer measuring no more than 3 mm thick would be obtained.

The principal quantity of ozone is concentrated at heights from 20 to 60 km, and its maximum concentration (0.000004% by volume) is found at heights from 45 to 55 km.

The role of ozone in the atmosphere, regardless of its negligible quantity, is extremely important. It absorbs the majority of the ultraviolet rays from the Sun which have wavelengths less than 290 millimicrons and have an extremely pronounced biological effect, as well as a certain amount of visible and infrared rays.

The amount of ozone in the air changes with latitude and time of year. The minimum is at the Equator and the maximum in the polar regions. As far as the time of year is concerned, the maximum ozone content occurs in spring, and the minimum in autumn.

Man can withstand an ozone concentration in the air equal to 0.0001 mg/l. Higher concentrations cause irritation of the upper respiratory tracts and lungs.

Rubber is destroyed and metals are considerably corroded at ozone concentrations of thousandths and hundredths of a percent.

Carbon dioxide is formed at the Earth's surface as a result of the vital activity of animals, bacteria, and to some extent plants, as well as on burning and decay. The content of this gas in the air varies and depends on local conditions. Due to the vertical movement of the air, the amount of carbon dioxide remains the same up to altitudes of 20 km as at the Earth's surface. There is none above that. It is believed that it disappears due to photochemical decomposition.

Carbon dioxide plays an important role in the regulation of the thermal regime of the lower layers of the atmosphere; it intensely absorbs the long-wave radiation, so that the air is heated.

The atmosphere also contains a small amount of suspended solid particles in the form of dust of inorganic and organic origin. This dust enters the /20
atmosphere from the Earth's surface. Most of the dust is at the Earth's surface. The amount decreases with altitude. At altitudes of 7 to 8 km, there is almost no dust of terrestrial origin (Table 1).

In the upper layers of the atmosphere, we find volcanic dust as well as cosmic and meteor dust, which comes in from interplanetary space and forms as a result of breakdown of meteors.

TABLE 1

Height above sea level, m	10	1000	2000	3000	4000	5000	6000	7000
Number of dust particles, 1 cm^3 of air	45,000	6000	700	200	100	50	20	6

Weight and Pressure of Atmospheric Air

The atmospheric air, like any substance, has weight. At sea level, at a temperature of 0° C and a pressure of 760 mm Hg, one cubic meter of dry air weighs 1293 g; at an altitude of 12 km it weighs 319 g, while at 40 km it weighs a total of 4 g (at standard temperature).

The mass of air located above the surface of the Earth is attracted toward its center, producing pressure both on the Earth's surface and on any object which is located on this surface and in the air. This pressure is called atmospheric. At sea level, atmospheric pressure is equal to 1.033 kgf/cm^2.

The weight of a column of air whose height is equal to the height of the Earth's atmosphere and measures 1 cm^2 at the base at 0° C and is at a latitude of 45° would be equal to the weight of a column of mercury 760 mm high with the same base area and under the same conditions. Atmospheric (barometric) pressure is usually expressed in millimeters of a mercury column. Thus, at sea level atmospheric (barometric) pressure would be equal to 760 mm Hg. At various locations, at different times of year and in different kinds of weather, it will change. The extreme values for barometric pressure that have been recorded thus far are 680 and 802 mm Hg.

The total atmospheric pressure is made up of the partial pressures of the gases that make up the air. /21

The partial pressure of a gas is the fraction of the pressure of a given gas in the total pressure of a gas mixture, i.e., the pressure which the gas would have in the event that it alone filled the entire volume occupied by this mixture.

As altitude increases, the total barometric pressure drops, so since there is a decrease in the height of the column of air and the density of the air.

If we assume that the total barometric pressure of the air at the surface of the Earth to be unity (1 atmosphere), the change in this pressure with changing altitude will be characterized by the data given in Table 2.

TABLE 2

Altitude, km	0	16	32	48	64	80	96
Pressure, atm	1	0.1	0.01	0.001	0.0001	0.00001	0.000001

With a decrease in the total barometric pressure with increasing altitude, there is a corresponding decrease in the partial pressure of the gases which go to make up the air. If we know the total barometric pressure at a given altitude, and the percentile content of gases, we can determine the partial pressure of any gas at any altitude. To do this, we use the following formula:

$$p = \frac{CB}{100}$$

where p — is the partial pressure of the gas;

C — is the percentile content of the gas in the air;

and B — is the total barometric pressure.

Of all the gases, oxygen is the one that is most important for the vital activity of man. Its partial pressure at sea level is 159 mm Hg. Percentile content of oxygen in the atmosphere remains fixed with altitude, but its partial pressure decreases. The latter has a critical influence on the provision of the organism with oxygen during the respiration process.

An example of the calculation of the partial pressure of oxygen is as follows: /22

for the Earth:

$$p_{O_2} = \frac{21 \cdot 760}{100} \approx 159 \quad \text{mm Hg;}$$

for an altitude of 6,000 m:

$$p_{O_2} = \frac{21 \cdot 354}{100} \approx 74 \quad \text{mm Hg;}$$

for an altitude of 10,000 m:

$$p_{O_2} = \frac{21 \cdot 198}{100} \approx 42 \quad \text{mm Hg.}$$

Air Density and Standard Atmosphere

The air density is the ratio of the mass of air to the volume which it occupies. Lower layers of the atmosphere are much denser than the upper ones. This is explained by the fact that air like any gas can be compressed under the influence of pressure.

The density of the air increases with decreasing temperature and increasing pressure. This also depends on the amount of water vapor in the air: the more there is, the less the density of the air.

The air density decreases with increasing altitude. At an altitude of 10 km, it is almost 1/4 that at sea level.

With the aid of rockets and artificial Earth satellites, it has been possible to determine the density of the atmosphere up to very great altitudes. The data obtained are very important for aviation and cosmonautics. For aviation calculations, it is necessary to have data on the average change in pressure, density, and temperature of the air and the speed of sound with altitude. The conditional distribution of these data with altitude for dry pure air is called the standard atmosphere.

In the USSR, the standard atmosphere for 1964 is valid (All-Union State Standard 4401-64). As the original data for its calculation, the barometric air pressure of 760 mm Hg and the temperature of 15° C at sea level were used.

The standard atmosphere for altitudes from 0 to 200 km is given in Table 3.

Solar Radiation /25

Solar radiation is a continuous flow of radiant energy from the Sun. Solar radiation consists of various forms of electromagnetic (wave-type) and corpuscular radiation.

The electromagnetic radiation from the Sun includes infrared rays, visible rays of light, ultraviolet, X- and gamma rays. Infrared rays have wavelengths of 2,300 - 800, visible light rays 800 - 400, ultraviolet rays 400-2, and x-rays 2 - 0.006 millimicrons. In 1942, solar radiation with a wavelength from millimeters to several meters was discovered.

The sources of corpuscular radiation are the solar corona (the external layer of the solar atmosphere) and the chromospheric flares, during which

TABLE 3 /23

Altitude, m	Temperature °C	Temperature °K	Barometric pressure, mm Hg	Air density, kgf/m³	Speed of sound, km/hr
0	15.00	288.15	760.00	1.2250	1225.0
500	11.75	284.90	715.96	1.1672	1218.1
1000	8.50	281.65	674.12	1.1117	1211.1
1500	5.25	278.40	634.30	1.0582	1204.1
2000	1.99	275.14	596.28	1.0066	1197.1
2500	—1.26	271.89	560.24	$9.5706 \cdot 10^{-1}$	1190.0
3000	—4.51	268.64	525.98	$9.0941 \cdot 10^{-1}$	1182.8
3500	—7.77	265.38	493.35	$8.6345 \cdot 10^{-1}$	1175.6
4000	—11.02	262.13	462.46	$8.1942 \cdot 10^{-1}$	1168.4
4500	—14.27	258.88	433.15	$7.7714 \cdot 10^{-1}$	1161.1
5000	—17.52	255.63	405.37	$7.3654 \cdot 10^{-1}$	1153.8
5500	—20.77	252.38	379.04	$6.9758 \cdot 10^{-1}$	1146.5
6000	—24.02	249.13	354.13	$6.6022 \cdot 10^{-1}$	1139.1
6500	—27.27	245.88	330.54	$6.2441 \cdot 10^{-1}$	1131.6
7000	—30.52	242.63	308.26	$5.9010 \cdot 10^{-1}$	1124.1
7500	—33.77	239.38	287.20	$5.5725 \cdot 10^{-1}$	1116.6
8000	—37.02	236.14	267.38	$5.2591 \cdot 10^{-1}$	1109.0
8500	—40.26	232.89	248.62	$4.9585 \cdot 10^{-1}$	1101.3
9000	—43.51	229.64	230.95	$4.6712 \cdot 10^{-1}$	1093.6
9500	—46.75	226.40	214.36	$4.3977 \cdot 10^{-1}$	1085.9
10 000	—50.00	223.15	198.70	$4.1357 \cdot 10^{-1}$	1078.0
10 500	—53.25	219.90	183.98	$3.8859 \cdot 10^{-1}$	1070.2
11 000	—56.49	216.66	170.19	$3.6485 \cdot 10^{-1}$	1062.2
11 500	—56.49	216.66	157.33	$3.3728 \cdot 10^{-1}$	1062.2
12 000	—56.49	216.66	145.44	$3.1180 \cdot 10^{-1}$	1062.2
12 500	—56.49	216.66	134.46	$2.8825 \cdot 10^{-1}$	1062.2
13 000	—56.49	216.66	124.30	$2.6648 \cdot 10^{-1}$	1062.2
13 500	—56.49	216.66	114.92	$2.4636 \cdot 10^{-1}$	1062.2
14 000	—56.49	216.66	106.24	$2.2776 \cdot 10^{-1}$	1062.2
14 500	—56.49	216.66	98.221	$2.1056 \cdot 10^{-1}$	1062.2
15 000	—56.49	216.66	90.810	$1.9467 \cdot 10^{-1}$	1062.2
15 500	—56.49	216.66	83.954	$1.7998 \cdot 10^{-1}$	1062.2
16 000	—56.49	216.66	77.616	$1.6640 \cdot 10^{-1}$	1062.2
16 500	—56.49	216.66	71.763	$1.5384 \cdot 10^{-1}$	1062.2
17 000	—56.49	216.66	66.350	$1.4224 \cdot 10^{-1}$	1062.2
17 500	—56.49	216.66	61.345	$1.3151 \cdot 10^{-1}$	1062.2

TABLE 3 (continued)

Altitude, m	Temperature °C	Temperature °K	Barometric pressure, mm Hg	Air density, kgf/m^3	Speed of sound, km/hr
18 000	—56.49	216.66	56.719	$1.2159 \cdot 10^{-1}$	1062.2
18 500	—56.49	216.66	52.443	$1.1242 \cdot 10^{-1}$	1062.2
19 000	—56.49	216.66	48.489	$1.0395 \cdot 10^{-1}$	1062.2
19 500	—56.49	216.66	44.834	$9.6114 \cdot 10^{-2}$	1062.2
20 000	—56.49	216.66	41.455	$8.8870 \cdot 10^{-2}$	1062.2
21 000	—56.49	216.66	35.443	$7.5983 \cdot 10^{-2}$	1062.2
22 000	—56.49	216.66	30.305	$6.4966 \cdot 10^{-2}$	1062.2
23 000	—56.49	216.66	25.912	$5.5550 \cdot 10^{-2}$	1062.2
24 000	—56.49	216.66	22.158	$4.7501 \cdot 10^{-2}$	1062.2
25 000	—56.49	216.66	18.948	$4.0621 \cdot 10^{-2}$	1062.2
26 000	—53.75	219.40	16.219	$3.4336 \cdot 10^{-2}$	1068.9
27 000	—51.01	222.14	13.910	$2.9085 \cdot 10^{-2}$	1075.6
28 000	—48.28	224.87	11.959	$2.4701 \cdot 10^{-2}$	1082.2
29 000	—45.54	227.61	10.295	$2.1007 \cdot 10^{-2}$	1088.7
30 000	—42.80	230.35	8.8777	$1.7901 \cdot 10^{-2}$	1095.3
32 000	—37.33	235.82	6.6401	$1.3078 \cdot 10^{-2}$	1108.2
35 000	—29.14	244.01	4.3522	$8.2842 \cdot 10^{-3}$	1127.3
40 000	—15.49	257.66	2.2191	$4.0003 \cdot 10^{-3}$	1158.4
45 000	—1.87	271.28	1.1732	$2.0086 \cdot 10^{-3}$	1188.6
50 000	0.85	274.00	$6.3441 \cdot 10^{-1}$	$1.0754 \cdot 10^{-3}$	1194.6
55 000	—2.59	270.56	$3.4326 \cdot 10^{-1}$	$5.8928 \cdot 10^{-4}$	1187.1
60 000	—19.75	253.40	$1.8092 \cdot 10^{-1}$	$3.3162 \cdot 10^{-4}$	1148.8
65 000	—36.89	236.26	$9.1245 \cdot 10^{-2}$	$1.7937 \cdot 10^{-4}$	1109.3
70 000	—54.00	219.15	$4.3761 \cdot 10^{-2}$	$9.2747 \cdot 10^{-5}$	1068.3
75 000	—71.09	202.06	$1.9790 \cdot 10^{-2}$	$4.5490 \cdot 10^{-5}$	1025.8
80 000	—88.15	185.00	$8.3564 \cdot 10^{-3}$	$2.0979 \cdot 10^{-5}$	981.6
85 000	—88.15	185.00	$3.3976 \cdot 10^{-3}$	$8.5303 \cdot 10^{-6}$	981.6
90 000	—88.15	185.00	$1.3834 \cdot 10^{-3}$	$3.4733 \cdot 10^{-6}$	981.6
95 000	—88.15	185.00	$5.6408 \cdot 10^{-4}$	$1.4170 \cdot 10^{-6}$	—
100 000	—63.93	209.22	$2.4310 \cdot 10^{-4}$	$5.3993 \cdot 10^{-7}$	—
110 000	—15.79	257.36	$5.8671 \cdot 10^{-5}$	$1.0583 \cdot 10^{-7}$	—
120 000	+59.09	232.24	$1.9165 \cdot 10^{-5}$	$2.6586 \cdot 10^{-8}$	—
150 000	+706.90	980.05	$3.8428 \cdot 10^{-6}$	$1.7682 \cdot 10^{-9}$	—
200 000	+953.61	1226.8	$1.0226 \cdot 10^{-6}$	$3.6109 \cdot 10^{-10}$	—

material is thrown out from the lower layers of the solar atmosphere. The radiation of the first type is called "solar wind", which is a continuous flow of plasma consisting primarily of protons and electrons.

The chromospheric flares on the Sun are accompanied by "eruptions" of streams of ionized plasma, charged particles (protons, alpha particles, electrons), nuclei of helium, oxygen and other elements, as well as an increase in the intensity of visible ultraviolet and X-radiation, gamma rays, radio noise, etc. The intensity of the corpuscular radiation may increase up to hundreds of thousands of particles per square centimeter. It is at this time that powerful magnetic storms occur on Earth, disrupting shortwave radio communications; brilliant displays of aurora are observed, there is a weakening of galactic radio noise, etc. The composition of the corpuscular radiation in chromospheric flares is not uniform. Thus, for example, the corpuscular radiation which accompanied the flare that took place on 23 February 1956 consisted entirely of protons.

The frequency and intensity of chromospheric flares increase with increasing solar activity and reach a maximum approximately every 11 years. Chromospheric flares of high intensity are relatively rare. A total of five such flares were observed from 1942 to 1956. In recent years, with the aid of satellites, it has been determined that solar flares of low intensity take /26
place on the average once a month. However, due to the slight rigidity of the radiation spectrum of these flares, they are not recorded on the Earth. The chromospheric flares on the Sun are very complex processes and have still been studied very little.

In passing through the Earth's atmosphere, the solar radiant energy is partially reflected, scattered and absorbed by molecules of the gases that make up the air, water vapor, and dust particles. The shortest rays (with wavelengths from 0.06 to 290 millimicrons) do not reach the surface of the Earth and are completely absorbed by the ozone layer. Infrared rays are absorbed primarily by water vapor in the atmosphere. Consequently, the more water vapor in the atmosphere, the fewer infrared rays reach the Earth's surface. The intensity of the solar radiation at the upper limit of the atmosphere is equal to 1.94 on the average and does not exceed 1.52 cal/cm^2/minute at the Earth's surface. With increasing altitude, the intensity of ultraviolet and infrared radiation increases. Ultraviolet radiation increases on the average by 3 to 4% for every 100 m of altitude.

Within allowable limits, solar radiation can have a favorable effect on the human organism, stimulating normal physiological processes. Under its influence, there is a considerable improvement in the general feeling of man, his attitude and performance of work. Especially valuable in this respect is the "biologically active" shortwave portion of the solar spectrum (with wavelengths from 300 to 365 millimicrons).

In addition to solar radiation, the atmosphere and the surface of the Earth are continuously bombarded by cosmic rays.

Cosmic Radiation

Cosmic space is saturated with various kinds of radiation. Here there are streams of charged and neutral particles as well as electromagnetic waves in the radio region, light waves, ultraviolet rays, X-rays and gamma rays.

Cosmic rays of galactic and solar origin as well as the shortwave radiation from the Sun are types of radiation which are of enormous importance under today's conditions. /27

Galactic cosmic radiation consists primarily of protons and alpha particles (98%). The remaining 2% is made up of the nuclei of lithium, beryllium, boron, carbon, oxygen, nitrogen, fluorine, etc. Near the Earth, it is largely screened by the latter's geomagnetic field and the atmosphere. Therefore, the intensity of galactic (primary) cosmic radiation on Earth is about 20 times less than in interplanetary space.

Thanks to their extremely high speeds of movement (about 500 km per second), cosmic rays have tremendous energy; this can be enough for them to be able to penetrate the entire thickness of the Earth's atmosphere. Among the cosmic rays, there are particles which have energies millions and hundreds of millions of times greater than the maximum energy of particles which are accelerated in the most powerful accelerators on Earth. Entering the Earth's atmosphere, fast particles collide with atoms of gases in the atmosphere and destroy them. As a result of the collisions, secondary cosmic rays are formed. This can give rise to particles with completely new properties.

Studies have shown that the levels of cosmic radiation at altitudes which are attained by modern aircraft, even during long flights, are not dangerous to man. A certain degree of danger might be posed by flights at great altitudes during powerful chromospheric flares on the Sun, when the doses of radiation can reach tens and even hundreds of rem in a short time.

The Magnetic Field of the Earth and the Radiation Belts

The Earth, like many cosmic bodies, has a magnetic field. Electrically charged particles which are within the limits of this field interact with it and, as a result, begin to move along magnetic lines of force. At the point of origin of the magnetic equator, the velocity of the particles reaches its maximum value.

Due to the capture and holding of electrically charged particles by the magnetic field of the Earth, zones or belts of increased radiation are formed in space near the Earth.

These belts form a colossal cloud consisting of electrically charged particles. To a certain degree, they can be divided conditionally into two /28
radiation belts: inner and outer (Figure 2).

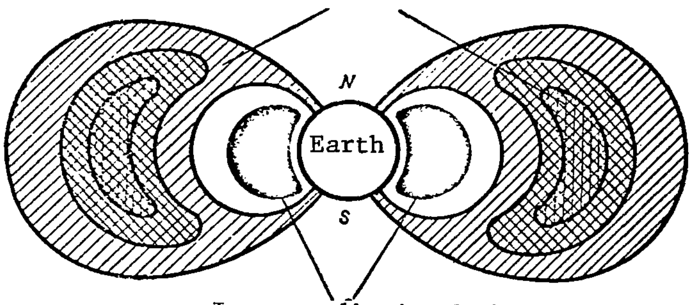

Figure 2. Radiation belts of the Earth.

The inner radiation belt of the Earth consists primarily of high-energy protons. In the Western Hemisphere, the lower limit of the belt passes at an altitude of 500 to 600 km, while in the Eastern Hemisphere it is at an altitude of approximately 1600 km. This difference in altitude is explained by the peculiarities of the magnetic field. The outer limit of this radiation belt is about 7,000 to 10,000 km from the surface of the Earth.

The maximum radiation intensity in the inner belt is observed at altitudes of 2500 to 3600 km. According to the latest data, there is also a second radiation maximum at an altitude of 7,000 to 8,000 km.

The outer radiation belt of the Earth is located 10,000 to 75,000 km from the Earth's surface. This radiation belt is formed primarily by electrons. The intensity maximum of the electron flux is observed in the equatorial plane at 15,000 to 20,000 km.

The radiation belts intersect one another, forming continuous fluxes of charged particles maintained by the magnetic field of the Earth. The maximum concentration of proton flux is observed at altitudes of 2500 to 3500 km. For /29
flights in this region of space near the Earth, crews must have special protection.

Temperature of the Atmosphere

The principal source of the heat received by the Earth is the Sun. For each square meter of the Earth's surface, an average of 14 to 18 large calories of heat are required each minute.

A large portion of the solar radiation which reaches the Earth's surface is absorbed by the latter and converted into thermal energy. From the surface of the Earth, the heat is transmitted to the layer of air adjacent to it. The heated air, being less dense and lighter, rises upward and cold air comes to take its place. The warm air, entering a region of reduced pressure, expands. To perform this work, a certain amount of thermal energy is used, so that the temperature of the air falls; within the limits of the troposphere, the temperature of the air decreases on an average by 0.65° C for every 100 m of altitude. This value is called the vertical temperature gradient.

The decrease in temperature is not always regular: at an altitude up to 2 km, we find deviations from the temperature calculated on the basis of the vertical temperature gradient. Sometimes, when rising to this altitude, we do not find a decrease but rather an increase in the air temperature. This phenomenon is called inversion. Inversion takes place due to irregular heating of the Earth's surface and violent mixing of air masses.

As altitude increases, the air cools and at a certain altitude the temperature decrease ceases. This altitude is called the boundary between the troposphere and the stratosphere. In middle latitudes, at this temperature boundary, the air temperature decreases to -56° C and at the equator — to -70 tc -80°C. This temperature in the stratosphere is maintained to an altitude of approximately 25 km, after which it begins to increase, reaching a maximum at an altitude of approximately 50 km.

The temperature decreases in the mesosphere at altitudes from 50 to 90 km. In the thermosphere, it increases, and at an altitude of 200 km it reaches 954, while at an altitude of 500 km, it reaches 1500° C. Above this, the temperature remains constant. As we have already pointed out above, under these conditions in the atmosphere, the temperature reflects only the rate of movement of gas particles. The heating of bodies will take place due to absorption of solar radiation. /30

The temperature of the air at the surface of the Earth varies considerably depending on the geographical latitude, time of year, and time of day. Formerly, the "cold pole" was considered to be the city of Verkhoyansk, where a temperature of -68° C was recorded. Later, a temperature of -71° C was recorded at the settlement of Oymyakon in the Yakut Autonomous SSR. And quite recently, Soviet meteorologists at the "Vostok" Station in Antarctica recorded a temperature drop to -88.3° C. The highest known temperature (+58° C) was recorded in Africa near the city of Tripoli.

CHAPTER III

BRIEF SURVEY OF HUMAN ANATOMY AND PHYSIOLOGY /31

Anatomy and physiology belong to the biological sciences which study living organisms. Anatomy is the science of the external shapes and internal structures of the organism, while physiology is the science of functions or actions of individual organs and the organism as a whole.

All of the cells, tissues, and organs of the body are functionally interrelated. The leading role in this linkage and in the control and regulation of all life processes of the organism is played by the nervous system. Stimulation of the nerve endings in one organ, transmitted through the central nervous system, has an effect on the activity of another. Thus, for example, painful stimulation of the nerve endings of some part of the skin causes contraction of a certain group of muscles and may lead to a change in the action of the heart, disruption of respiration, etc.

In addition to the functional relationship between the cells, tissues and organs, there is also a chemical link which operates through the blood and lymph. The essence of this relationship consists of the fact that substances which are formed during the activity of certain organs enter the blood, which carries it through the entire organism, stimulating or suppressing the activity of other organs. Thus, for example, substances liberated by the adrenal glands exert an influence on the action of the heart and the intestine. This form of communication is also under the control of the central nervous system. "There is no part of the human organism which could exist alone, without any connection to other parts; but none of the parts of our body is linked so vitally with the others as the brain"[3].

The theory of the body as a single whole also includes the assumption of an immutable link between the psychic and corporeal. The psychic activity is a function of highly organized matter, the brain. /32

The structure and activity of the body are always adapted to certain conditions of existence. Any change in these conditions causes a change in the structure and function of its organs.

"The body," wrote I. M. Sechenov, "is impossible without an external medium supporting its existence; therefore, the scientific determination of a body must involve the medium which affects it, since existence of the body without the latter is impossible"[4]. Consequently, the structure and vital activity of the body can only be understood by studying it in conjunction with the conditions of existence.

In regard to man, it is necessary to consider not only the biological, but also the social, laws which to a large extent determine his development and activity.

Cells and Tissues

The human body has a cellular structure, i.e., it consists of a large number of cells.

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(3) N. A. Dobrolyubov: Izbrannyye Filosofskiye Proizvedeniya (Selected Philosophical Excerpts). Vol. 1, 1948, p. 249.

(4) I. M. Sechenov: Meditsinskiy Vestnik. St. Petersburg, No. 26, 1861. p. 242.

Cells differ considerably in shape, size and structure (Figure 3). According to modern views, the cell is a microscopically small organ of a complex organism, in which certain vital processes take place. The living cell obtains necessary nutrient substances from the medium surrounding it as well as oxygen and gives off unnecessary substances to this medium (carbon dioxide, etc.). Hence, there is a continuous exchange between the cell and the surrounding medium, without which life would not be possible. "Life", wrote Engels, "is the ability of protein bodies to survive, with the crucial factor being the constant exchange of substances with external nature surrounding them, so that cessation of this exchange will lead to termination of life itself, and to a breakdown of the protein"(5). /34

The cells which carry out certain vital functions join together to form fundamental tissues (nervous, connective tissue, cartilage, bone, muscle, epithelium, etc.) while the tissues in turn form organs.

Organs and Organ Systems

Each organ in the human body has a certain function to perform: the heart, contracting rhythmically, moves the blood through the vessels; the lungs provide gas exchange between the body and the external medium, etc.

In accordance with their basic functions, the organs form organ systems. These systems include the nervous system, the sense organ system, the respiratory system, the circulatory system, the support-motor system, excretory system, digestive system, as well as systems of endocrine glands and reproductive organs.

The support-motor system consists of the skeleton and the transversely striated muscles; the circulatory system consists of the heart and the blood vessels; the respiratory system consists of the nose, pharynx, larynx, trachea,

(5) Friedrich Engels: Dialektika Prirody (Dialectics of Nature). "Gospolitizdat" Press, 1952, p. 244.

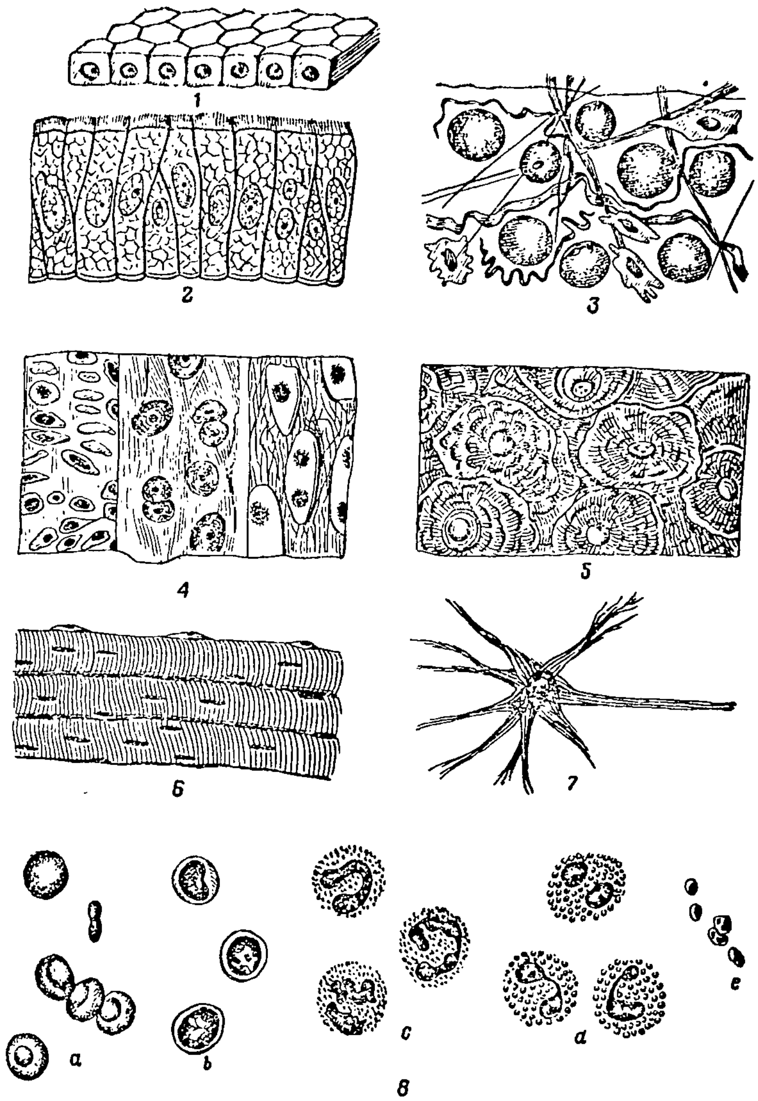

Figure 3. Structure of cells and tissues.

1 - cuboidal epithelium; 2 - cylindrical epithelium; 3 - connective tissue; 4 - cartilage tissue; 5 - bone tissue; 6 - muscle tissue; 7 - nerve cell; 8 - blood: a - erythrocytes, b - lymphocytes, c - neutrophiles, d - eosinophiles, e - blood platelets (thrombocytes).

bronchi and lungs; the digestive system consists of the oral cavity, pharynx, esophagus, stomach, intestine, pancreas, and liver; the excretory system consists of the kidneys, ureters, and urinary bladder; the nervous system consists of the brain and spinal cord, as well as sensory and motor nerves.

Differentiated in structure and purpose, possessing a certain degree of independence, all of the systems and organs still function in a very close interrelationship.

Nervous System

The idea of the dominant role played by the nervous system in the entire reaction of the organism to the influence of external or internal media, i.e., the idea of nervism, was developed most completely in the teachings of I. P. Pavlov regarding higher nervous activity, which forms the natural scientific /36 materialistic basis of Soviet biology and medicine.

Nerve cells and their branches form the basis of nerve tissue.

The nervous system (Figure 4) is divided into the central (brain and spinal cord) and peripheral (craniocerebral and cerebral spinal nerves) sections.

A great many nerve fibers run from the brain and spinal cord. There are motor and sensory nerve fibers. The former carry impulses from the central nervous system to the organs and tissues, causing them to act, while the second have the opposite effect: they run from the organs and tissues to the central nervous system. In addition to the motor and sensory functions, the nervous system also has a so-called trophic function (from the word "trophics" — nourishment). It affects the metabolism in the organism and regulates the nourishment of tissues and organs.

The brain consists of five parts: two hemispheres (right and left), the diencephalon, mesencephalon and the medulla oblongata as well as the cerebellum.

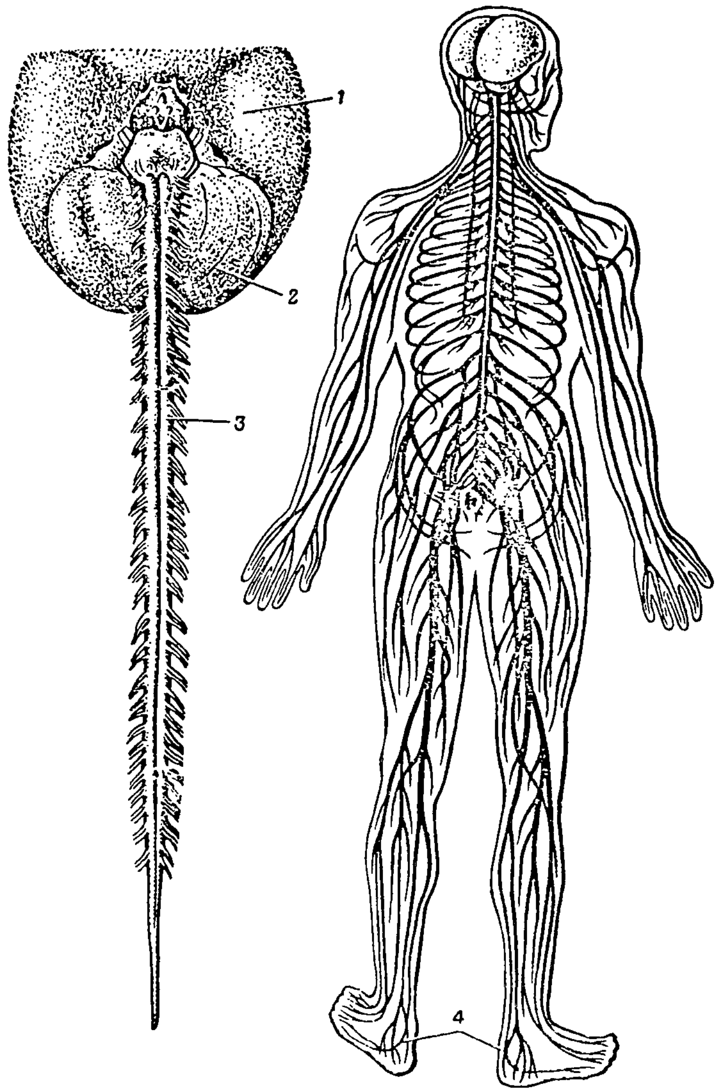

Figure 4. Human nervous system.

1 - cerebrum; 2 - cerebellum; 3 - spinal cord;
4 - peripheral nerves.

The largest part is made up of the hemispheres. The surface of the brain is streaked with furrows and convolutions. The outer layer of the cerebrum is called the cortex. The cortex contains all of the furrows and convolutions of the brain. It is 20 m^2 in size. The cortex consists of about 16 billion nerve cells, differing in structure and function. The cerebral cortex is the most important part of the central nervous system; without it, psychic activity of the human being is impossible.

The cortex has areas or centers, each of which performs a specific function. For example, the visual center is located in the occipital region, the auditory center is located in the temporal region, and so on.

To control the activity of the organism, it is necessary for certain (various) stimuli to reach the cerebral cortex (signals) from the surrounding medium and from the internal organs. These stimuli are detected by specially equipped nerve endings in the tissues and organs. These are called receptors.

The receptors of the organs of vision, hearing, olfaction and taste as well as the receptors in the skin perceive pain, temperature, tactile, light, chemical and other stimuli, received from the environment. /37

The receptors in the muscles, ligaments, and joints detect stimuli that arise in them due to changes in the position of the human body in space and posture. The sensation which develops as a result of this detection is called the muscle-joint sense.

Stimuli that develop in the internal organs (heart, lungs, liver, etc.) are transmitted to the cerebral cortex from receptors in these organs.

Thanks to the receptors, there is a link between the cortex and the external world and the internal medium of the organism itself. The receptors, with nerve fibers running from them to corresponding centers in the brain, form a single functional system which I. P. Pavlov called an "analyzer". The name of "analyzers" was chosen by him to emphasize their importance for the analysis of phenomena of the external and internal medium.

The highest center of the analyzer is the corresponding portion of the cerebral cortex.

I. P. Pavlov called the cerebral cortex a complex analyzer. The signals that are obtained from the external world in the cerebral cortex are not only analyzed (sorted and selected) but synthesized (linked and compared) in its nerve cells. Thus, the cortex carries out a high level of analysis and synthesis of all complex vital functions. Consequently, the human organism is a single functionally linked system, which is in close interaction with the surrounding medium.

Pavlovian teachings regarding analyzers are in complete agreement with the Marxist-Leninist view, according to which "sensation is a real direct link of the consciousness with the external world; it is conversion of the energy of the external stimulus into perception"(6).

The spinal cord runs inside the spinal column. The spinal cord is 40 - 45 cm long, and has an average diameter of 1 cm. The spinal cord consists of nerve cells and fibers. Thirty-one pairs of spinal nerves branch out from it, constantly branching further and penetrating all the tissues and organs. Both motor and sensory fibers make up the cerebrospinal nerves. Impulses created by the contraction of muscles travel over the motor fibers /38
from the center to the periphery (to the muscles, skin, etc.), while stimuli detected by nerve endings in the tissues and organs travel over the sensory fibers from the periphery toward the center. Thus, the cerebral spinal nerves link the periphery of our body with the central nervous system.

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(6) V. I. Lenin. Complete Collected Works. Vol. 18, p. 46.

Activity of the central nervous system. The basis of the activity of the nervous system is the so-called reflex. A reflex is understood to be the responsive reaction of the organism to some stimulus, created by the central nervous system. For example, when an individual's hand is cut or burned, he withdraws it, since the nerve endings in the skin are stimulated. From these endings, the stimulus passes along the sensory nerve fibers to the spinal column, where it is transmitted to motor nerve fibers from the sensory nerve fibers. The stimulus passes over the motor nerve fibers to the muscles of the hand. This is a pathway or an arc of the reflex. When the impulse is transmitted to the muscles, they contract, so that the hand is withdrawn.

According to the teaching of I. P. Pavlov, there are unconditioned and conditioned reflexes. Unconditioned reflexes are congenital and are transmitted by inheritance. Reflexes which are acquired by man in the course of his life under the influence of the surrounding medium are called conditioned. Pavlovian teachings regarding conditional reflexes have played an enormous role in the discovery of the basic laws of higher nervous activity of animals and man.

The link of the organism with the external medium is accomplished on the basis of unconditioned and conditioned reflexes. For example, if some food enters the mouth of an animal, its contact with the mucous membrane of the oral cavity will stimulate the nerve endings of the cavity, and saliva will begin to flow. Such a response reaction to a stimulus is an unconditioned reflex. If the animal is exposed to some indifferent stimulus such as a sound or light at a certain time prior to each feeding, the animal will salivate when the signal alone is given after several applications of such a /39
stimulus. This will be the result of a conditioned reflex.

Conditioned reflexes are very important for man as well, since they link him to the external world through the establishment of temporal nerve connections and the extinction of links which lose their value for the vital activity of the organism.

On the basis of conditioned reflexes, I. P. Pavlov showed the extreme importance of the signal activity of the cerebral cortex of the brain. It is very important for the organism that the cerebral cortex be able to signal what must be done as a result of a reflex action that has occurred. Thanks to this, the organism is better prepared for various external and internal stimuli.

With the passage of time, the cortex develops and stores temporal nervous connections which are accumulated by an individual as a result of individual experience. These links make his life much easier.

Man and the animals obtain signals from the external world through the organs of vision, hearing, olfaction and so on. The mechanism which makes it possible to obtain signals through these organs was called by I. P. Pavlov the "first signal system of reality", thanks to which man not only picks up direct sound, visual and other stimuli, but can also develop for himself an idea about them through the visible and audible word. Due to verbal signalling, man can sense reality mentally.

The second signal system of reality plays the predominant role. I. P. Pavlov wrote: "In the developing animal world, in the human phase, there has been an extreme increase in the mechanisms of nervous activity. For an animal, activity is signalled almost exclusively by stimuli and their traces in the cerebral cortex, arriving directly at special cells of the visual, auditory and other sectors of the organism. This is what we think of as impressions, sensations and ideas regarding the external medium around us, both that of nature in general and our social world, excluding words, audible and visible. This is /40 the first signal system of reality, which we have in common with the animals. But the words have created a second signal system of reality which is special for us, being the signal of the first signals"[7].

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(7) I. P. Pavlov. Uslovnyy Refleks (The Conditioned Reflex). Collected Works, Vol. III, Book 2, 1951, pp. 335-336.

Analyzers (Sense Organs)

The ability to analyze phenomena of the external and internal medium is the most important function of the central nervous system.

Under the influence of a stimulus, an excitation develops in receptors which travels over the nerve fibers to the cortex of the brain where it forms the sensation of light, sound, taste, pain or some other sensation, depending on which receptors were subjected to stimulation and what parts of the cortex receive the stimulus. Thus, in order for any of the sensations to arise, it is necessary that receptors, nerve fibers and a corresponding segment of the cerebral cortex, i.e., analyzers, have participated in this process.

The visual analyzer (organ of sight). An extremely important role in human life and its interaction with the external world is played by vision — the most important physiological process. By means of vision, we recognize the shape, size and color of objects, get an idea of their mutual positions, movement and distance, and thus acquire the ability to orient ourselves in surrounding space.

The visual analyzer consists of the eye, the optic nerve and visual center in the occipital region of the cerebral cortex.

The eye is a complex optical system (Figure 5). The eyeball has the shape of a sphere with three layers. The outer layer is called the sclera, while the transparent part in front is called the cornea. Light rays can enter the eyeball only through the cornea. The choroid is located beneath the sclera. It is richly provided with blood vessels that nourish the eye. The anterior portion of the choroid, located behind the cornea, is called the iris. In its center there is an opening called the pupil. The iris acts as a diaphragm. /41
Behind the iris, opposite the pupil, there is a crystalline lens, which may be compared with a biconvex optical lens. The entire cavity of the eyeball is

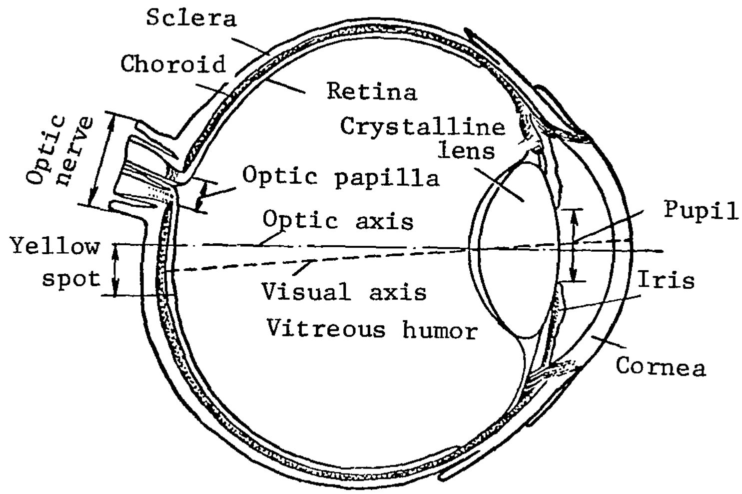

Figure 5. Cross section of the human eye.

filled with a so-called vitreous humor. The cornea, crystalline lens and vitreous humor are transparent. The light rays passing through these three media are refracted and strike the inner lining of the eye, called the retina. This covers only the posterior half of the cavity of the eye, and it contains light sensitive endings of visual receptors — rods and cones. Everybody's eye has about 130 million rods and about 7 million cones. The rods contain the photochemical substance rhodopsin, while the cones contain iodopsin. The sensitivity of each substance depends on the degree of concentration of its decay products.

The cones are located primarily at the center of the retina, opposite the center of the pupil (along the visual axis). In the middle of the retina is a depression (sometimes called the yellow spot) which contains only cones. The number of cones decreases outward toward the periphery from the center of the yellow spot. The rods are located only on the periphery of the retina. From each cone and from each group of rods (about 100 rods per group) there runs a /42 fine nerve fiber which reaches the visual center in the middle of the optic nerve in the occipital region of the cerebral cortex.

The light which enters the eye affects the photochemical substances (rods and cones) and breaks them down, causing a photochemical reaction. The breakdown products of these substances, on reaching a certain concentration, stimulate the nerve endings in the rods and cones. The nerve impulses which are generated by this process travel along the fibers of the optic nerve to the visual center in the brain and cause visual impressions in our mind.

The functions of the rods and cones differ considerably. First of all, the cones are able to detect stimulation only at a certain brightness of the object and are elements of "daytime" vision, while the rods react to weak illumination and serve for "nighttime" (crepuscular) vision. In the second place, the "cone" (central) vision is sharp, making it possible to distinguish fine detail; however, the vision provided by the rods (peripheral) is dull and makes it possible only to orient one's self in space. In the third place, the detection of colors is accomplished only by means of the cones in the retinal apparatus.

Visual acuity. In order for an individual to determine the shape of an object, his eye must be able to make out the outlines and limits of this object. This ability of the eye is called visual acuity, the ability of the eye to distinguish two points located some distance apart. It is measured by the minimum angle at which two points can still be detected as separate. Practically speaking, visual acuity is determined with the aid of objects (tables) which are viewed at a certain distance from the subject (5 m), which provide an image in the eye at a visual angle from 0.5 to 10'.

Oculomotor apparatus. The movement of the eyes is accomplished with the aid of three pairs of muscles, which rotate the eyeball in its orbit. The movements of the muscles of both eyes are synchronized, so that individual movement of one eye without similar movement of the other is impossible. In /43 examining close objects, the visual axes converge, and in looking at objects at an infinite distance, the axes become parallel. Muscular balance and the position of the eyes are achieved by corresponding tension and relaxation of their muscles.

The object being viewed is imaged simultaneously in both eyes; we do not see it as double, but as a single object at a specific spot.

Visual estimation is judging distances by eye and is of great importance when it is necessary to distinguish how close or far away objects are located. Visual estimation is particularly important in flight. Correct estimation of distances depends on the muscle apparatus of the eye and the state of the organ of vision as a whole.

Auditory analyzer (organ of hearing). The principal function of the auditory analyzer is the detection of sound oscillations with frequencies from 16 to 20,000 cycles* per second.

The ear consists of the detecting portion of the analyzer. Usually, it is divided into the outer, middle, and inner ear (Figure 6).

The outer ear consists of the concha auriculae and the outer auditory passageway. The inner end of this passageway is closed by an elastic membrane called the eardrum, which divides the outer and middle ear. /44

Immediately behind the eardrum is the cavity of the middle ear, in which the so-called ear bones are located: the malleus, incus and stapes. The system of ear bones serves for transmitting sound oscillations from the eardrum to the inner ear, where the organ of Corti is located that detects auditory stimulation (named after the Italian scientist Corti). The stapes (resembling a small stirrup) is mounted in the so-called oval window of the inner ear and completes the system for transmitting sound vibrations.

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*Translator's Note: The word "cycles" was omitted in the foreign text.

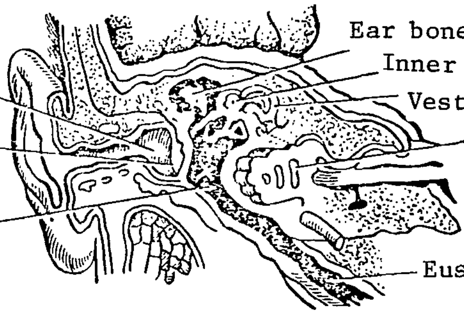

Figure 6. Schematic cross section of the ear.

The cavity of the middle ear is connected to the nasopharyngeal cavity by means of the eustachian tube, a special channel along which air travels during swallowing from the nasopharynx to the cavity in the middle ear.

The inner ear is characterized by a most complex device. It consists of three parts: the saccules of the vestibulum, the cochlea and three semicircular canals. All three parts, located in a temporal bone in the skull, form a complex bony labyrinth, within which is located the membranous labyrinth which repeats its form exactly. Sound stimuli are picked up by the cochlea. The saccules of the vestibulum and the semicircular canals form the organ of equilibrium. The labyrinth is filled with fluid.

The cochlea consists of a spiral channel. Any oscillation of the eardrum and the ear bones causes a movement of the liquid which fills the cochlea. The cochlea contains the so-called basilar membrane, which consists of more than 20,000 transversely stressed fibers of different length, which resemble strings. The organ of Corti runs along the entire basilar membrane. The most important part of this organ are cells with very fine hairs. These cells also serve as receptors that pick up auditory stimuli.

Sound waves from the surrounding medium enter the external auditory passageway and set the eardrum vibrating. This vibration is transmitted through the chain of ear bones to the cavity of the cochlear channel of the inner ear. The vibrations of the liquid in the cochlear channel are transmitted, and set in motion the fibers on the basilar membrane. The fibers vibrate and set the cells of the Corti organ in motion. As a result, a nerve impulse develops which is directed to the corresponding portion of the cerebral cortex where a corresponding sound image is synthesized. /45

The vestibular analyzer. The peripheral portion of the vestibular analyzer (apparatus) is located in the saccules of the vestibulum and the semicircular canals of the inner ear.

In the inner cavities of the saccules of the vestibulum, there are accumulations of special nerve cells. One end of each of these cells is narrow and ends in a short hair which point into the cavity of the saccule. Small calcareous crystals rest on the ends of these hairs; they are called otoliths. The nerve cells, hairs, and otoliths form the otolithic apparatus (Figure 7).

When the position of the head or the entire body is changed, during vibration, acceleration, or deceleration of linear movement, the otoliths move and press on the fibers which have sensitive cells beneath them. This causes formation of a chain of nerve impulses which run to the medula oblongata and from there to the cerebellum and the cerebral cortex. Under the influence of these impulses, reflexes develop which change the stress of skeletal muscles and make it possible to retain normal position of the body in space. /46

Semicircular canals (Figure 8, a, b). These are narrow and have the shape of semicircles located in three mutually perpendicular planes (Figure 8, c). The cavity of the channels is filled with liquid which moves during acceleration or deceleration of rotational movement. As it moves, the liquid creates a stimulation which is picked up by nerve cells on the walls of the expanded ends of the canals. In these cells, nerve impulses develop which travel to

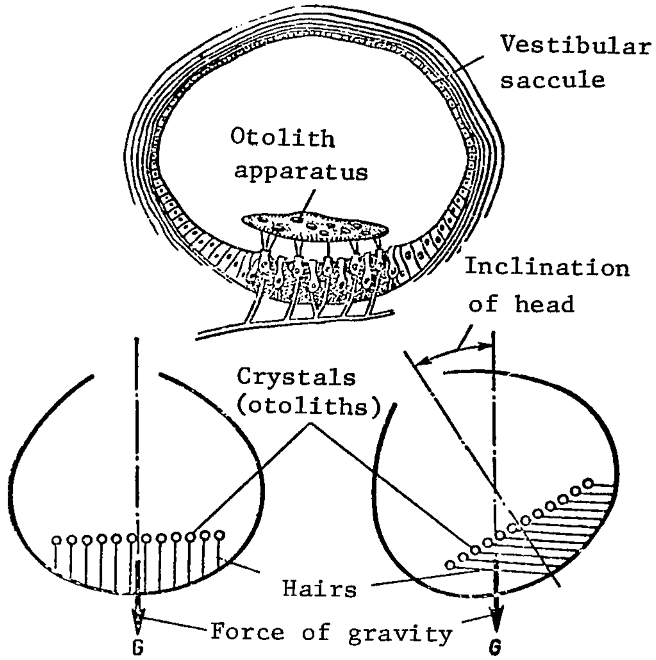

Figure 7. Diagram of otolith apparatus.

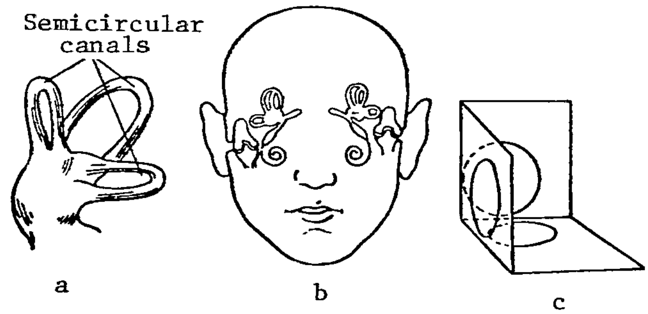

Figure 8. Diagram of vestibular apparatus.

the brain. In the brain, they set off a number of reflexes which make it possible to form a so-called three-dimensional sensation, i.e., they help to determine and retain the corresponding position of the body in space.

Disruption of the function of the vestibular apparatus (saccules of the vestibulum and semicircular canals) may cause a feeling of dizziness and nausea and an incorrect idea of one's position in space.

Normal operation of the vestibular analyzer is especially necessary for persons engaged in aircraft work, since their activity has to do with frequent changes of the body's position in space. /47

The motor analyzer is the organ of muscle-joint sensation. It is of enormous importance for performance and coordination of movements, in the detection of the body's position in space, and the development and retention of certain muscle stress (muscle tone).

In changing the stress of the muscles, nerve endings are stimulated which are located in the muscles, tendons, ligaments, and joints. The stimulus which arises as a result travels along the nerve fibers to the cerebral cortex where a concept of the body's position is formed.

Due to the muscle-joint sensation, a pilot is able to develop the ability to determine the magnitude of the forces which are required for operating the controls of the aircraft.

Touch (tactile) analyzer. The function of the touch (tactile) analyzer involves determining the nature of the surface of objects (smooth, rough, dry, wet), their shape, hardness, elasticity, softness, etc.

Touch receptors are located in the skin and are stimulated by touch and pressure. The stimulus that develops along the nerve fibers reaches the spinal cord and then the cerebral cortex, where it forms corresponding impressions.

* * *

As we can see from the preceding material, in man the function of orienting the position of the body in space is accomplished with the aid of various analyzers. Only the coordinated activity of the visual, vestibular, tactile, auditory and odor analyzers will give him the most complete information regarding spatial relationships of the organism and the medium. A critical role in this regard is played by the visual analyzer.

Heat and cold analyzers. The detection of temperature of the surrounding medium has to do with the effect of heat and cold, respectively, on the heat /48
and cold receptors, located in the skin and mucous membranes. When these receptors are stimulated, nerve impulses are formed which travel through the spinal cord and reach the cerebral cortex where they create impressions of heat or cold.

Taste analyzer. The peripheral portion of the taste analyzer consists of buds which are located primarily on the surface of the tongue. Stimulation of taste buds is accomplished by chemical compounds which are dissolved in the saliva. The sensation which arises in the taste buds travels over the neural conductors to the taste center in the temporal region of the cerebral cortex. where detection of a specific taste sensation is recorded. Man can taste four primary taste sensations: salty, acid, sweet, bitter. There is also such a thing as complex taste (aftertaste), which is a combination of the various tastes, as well as smell and other sensations.

The olfactory analyzer picks up smells of different substances. Its peripheral portion is located in the nasal cavity. In the mucous membrane of the nose, there are olfactory cells which consist of oval bodies with two long processes. One process picks up the stimuli, while the other enters the olfactory nerve and transmits the stimuli to the brain.

Respiratory System

The organs of respiration are designed for gas exchange between the organism and the atmospheric air, i.e., for providing the organism with oxygen and getting rid of carbon dioxide.

The respiratory system consists of the respiratory tracts and lungs (Figure 9). The respiratory tracts are made up of the nose, pharynx, larynx, trachea and bronchi. The lower end of the trachea of the respiratory throat divides into two bronchi, which pass into the right and left lungs. Within the lungs, the bronchi break down into very fine branches that terminate in fine pulmonary vesicles or alveoli. The diameter of an alveolus is about 0.2 mm (Figure 10). Hence, the lungs consist of a system of bronchi and alveoli, closely intertwined with blood vessels (capillaries). Diffusion of oxygen and /50
carbon dioxide takes place in the alveoli.

The lungs contain on the average about 700 million alveoli, whose total surface adds up to about 90 to 120 m^2. This allows rapid saturation of the blood with oxygen and removal of carbon dioxide from it.

The air which is contained in the lungs is constantly being changed. This change occurs during inspiration and expiration. During inspiration, due to contraction of the intracostal muscles, the volume of the chest cavity increases, expands, and the lungs expand as well, so that the atmospheric air rushes into them through the respiratory tracts. During expiration, the opposite process takes place.

An adult man in a state of rest takes about 16 to 18 breaths per minute. During work, the frequency of respiration increases to a degree which increases with the strenuousness of the physical stress.

In the ordinary resting position, each breath drawn into the lungs by a human being draws in about 500 m^3 of air. This air is called respiratory.

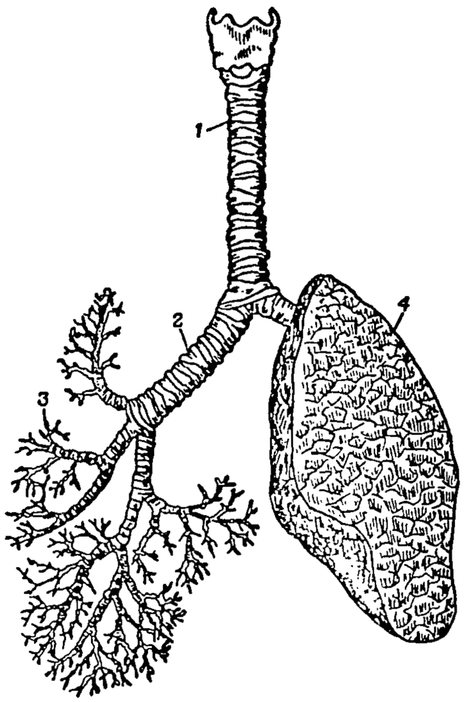

Figure 9. Human lung:

1 - trachea; 2 - right bronchus;
3 - bronchial tree; 4 - lung.

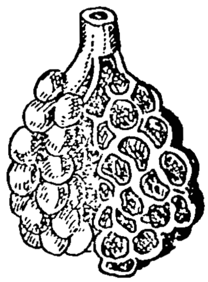

Figure 10. Pulmonary alveolus.

Following a quiet inspiration, a man can expel (by stressing his respiratory musculature) an additional 1500 cm^3 of air on the average. This air is called supplemental. Following a quiet expiration, a man can expire a further 1500 cm^3 of air. This air is called reserve. The maximum amount of air which a man can expire following the deepest inspiration is called the vital capacity of the lungs. In adult humans, this can reach 3,000 to 6,000 cm^3, and sometimes more. The vital capacity of the lungs is one of the most important indicators of the physical development of the individual and can be increased as a result of training the respiratory musculature.

Following the deepest possible expiration, about 1500 cm^3 of air still remains in the lungs. This is called residual. Consequently, the total amount of air in the lungs is equal to the sum of the vital capacity and the volume of residual air.

The exchange of the air in the lungs which takes place in the process of respiration is called pulmonary ventilation. In a state of rest, human lungs can circulate 6 to 7 liters of air per minute. Pulmonary ventilation increases /51 with an increase in physical stress. In a pilot, it can increase during flight in the case of insufficient oxygen or due to nervous and emotional stresses.

During the respiration process, there is diffuse exchange of gases between the blood and the alveolar air (Figure 11), which differs considerably from atmospheric in composition (Table 4) and partial gas pressure (Table 5).

On inspiration, approximately two-thirds of the air reaches the alveoli /52 and participates in gas exchange, while nearly one-third remains in the respiratory tracts. The space filled by air that does not participate in the gas exchange is called "dead space". In an adult man, the volume of "dead space" equals 140 to 150 cm^3.

Gas exchange between alveolar air and blood takes place through the wall of the alveolus. The thickness of these walls is insignificant, approximately

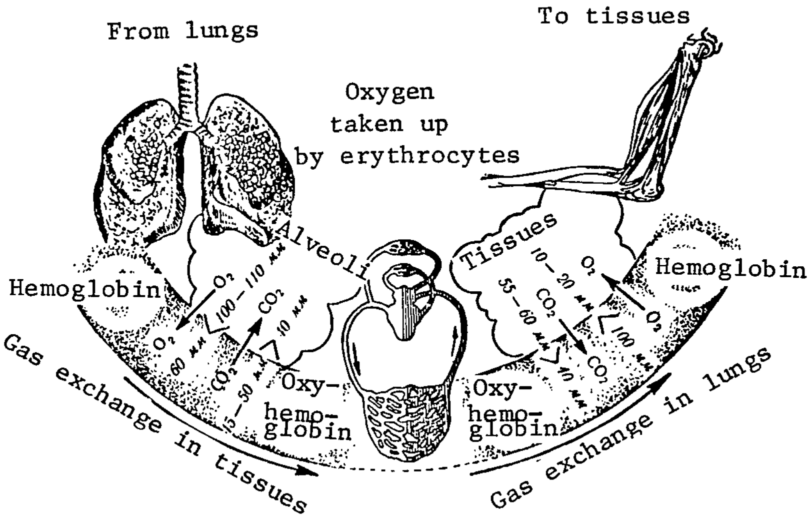

Figure 11. Diagram of gas exchange in lungs and tissues.

TABLE 4

Air	Percentile content		
	O_2	CO_2	N_2
Atmospheric (inspired)	20.93	0.03	78.03
Expired	16.4	3.08	79.8
Alveolar	14.5	5.6	79.9

TABLE 5

Air	Partial pressure* (mm Hg)			
	CO_2	N_2	O_2	H_2O
Dry atmospheric	1	600	159	-
Alveolar	40	573	100	47

*At sea level

four microns. They consist of a single layer of epithelial cells and blood-carrying capillaries.

The transition of the oxygen from the alveolar air to the blood and of carbon dioxide in the opposite direction is explained by the law of diffusion. According to this law, gas always moves from the medium where its partial pressure is greater to the medium where it is less. The partial pressure of oxygen in alveolar air is much higher than in the venous blood reaching the lungs. Therefore, the oxygen passes into the blood through the walls of the alveoli and capillaries. In turn, the carbon dioxide from the venous blood (here its partial pressure is greater than in the alveolar air) moves into the alveoli, and is excreted from the organism during expiration.

The venous blood, after giving up carbon dioxide in the lungs and being enriched with oxygen, returns to the arteries. Arriving at the heart from the lungs, it is distributed through all of the tissues and cells of the body.

An oxidation process is always in progress in the tissues, so that the oxygen is absorbed and carbon dioxide given off. Hence, the partial pressure of oxygen in them is low, while the carbon dioxide content is high. The blood which has passed through the tissues gives up a part of its oxygen to them and is enriched with carbon dioxide; it then returns to the veins. Moving through /53
the veins of the systemic circulation, it travels to the right heart and then into the lungs, where it again becomes arterial blood.

Circulatory System

The blood provides the cells with nutrient substances and oxygen; it removes the products of metabolism, formed as a result of the vital activity of cells; it maintains connection between the organs, transporting the substances which they excrete. It plays an important role in protecting the organism against the bacteria that cause various diseases.

An extremely sharp change in the composition and properties of the blood, for whatever reason, leads to a different type of disturbance in the organism.

The weight of the blood in the human organism is equal to about 1/13 of the body weight. This means that an adult man weighing about 70 kg will have 5 - 6 liters of blood. The blood consists of a liquid portion (plasma) and formed elements (cells) of the following types (Figure 3): erythrocytes (red blood cells), leucocytes (white blood cells) and thrombocytes (blood platelets).

The erythrocytes are enucleate cells similar in form to biconcave disks with a diameter of approximately eight microns and a thickness of about two microns. One mm^3 of blood from an adult human being contains 4.5 to 5 million erythrocytes. This quantity may increase or decrease depending on the state of the organism.

The physiological role of the erythrocytes is determined by the presence of hemoglobin in their composition. Hemoglobin is a combination of protein with heme, the principal coloring agent whose composition includes iron. Hemoglobin has the ability to bind oxygen energetically. As blood passes through the capillaries of the lungs, an unstable chemical compound of hemoglobin and oxygen called oxyhemoglobin is formed.

The erythrocytes absorb oxygen through their surfaces and carry it from the lungs to the tissues. Consequently, the greater the total surface of the erythrocytes ("respiratory surface"), the better and faster the process of gas exchange in lungs and tissues will proceed. At small sizes (but large numbers) /55
of erythrocytes, their area of "respiratory surface" will be very large.

Leucocytes are colorless or white, possess a nucleus and are cells that measure 7 - 15 microns. In 1 mm^3 of blood from a normal adult, there are 6,000 to 8,000 leucocytes. Their number may increase or decrease depending on the state of the individual. In the physiological scheme, leucocytes perform a protective function in the organism — they destroy germs that enter the blood and tissues.

Thrombocytes (blood platelets) are extremely small cells. One mm^3 of blood contains from 100,000 to 250,000 thrombocytes. In case vessels should break and hemorrhaging takes place, the thrombocytes are the centers around which clotting of the blood begins.

Blood circulation. Blood is in constant motion. Cessation of its movement will cause death, since all organs and especially the brain are very sensitive to oxygen deficiency and a lack of nutrient substances. Continuity of blood flow is maintained by the circulatory system, which consists of the heart and blood vessels.

The heart (Figure 12) is a hollow organ made primarily of muscle tissue. The heart may be compared with a pump, which forces blood into the arteries at certain intervals and imparts to it a certain velocity. The cavity of the heart is divided by a continuous septum into two halves, the right and the left. Each half consists of two similar parts, the ventricle and auricle. Hence, the heart has four chambers: the right auricle and right ventricle, left auricle and left ventricle.

The blood vessels include the arteries, veins and capillaries (Figure 13).

The blood travels through the arteries to all of the organs and tissues after it has been enriched with oxygen and nutrient substances from the heart; it travels in the opposite direction through the veins, from the organs and tissues to the heart. Venous blood is poor in oxygen and nutrient substances.

The capillaries are very fine vessels which connect the small arteries with the smallest veins. The length of the capillaries is 0.5 mm, while their diameter is 0.008 to 0.01 mm. Exchange of substances and gases between the /57
blood and the cells of the body takes place through their walls. The blood circulates in the organism through the greater and lesser circulations.

The greater circulation (Figure 14). When the heart muscle contracts, the blood is forced out of the left ventricle (where the greater circulation

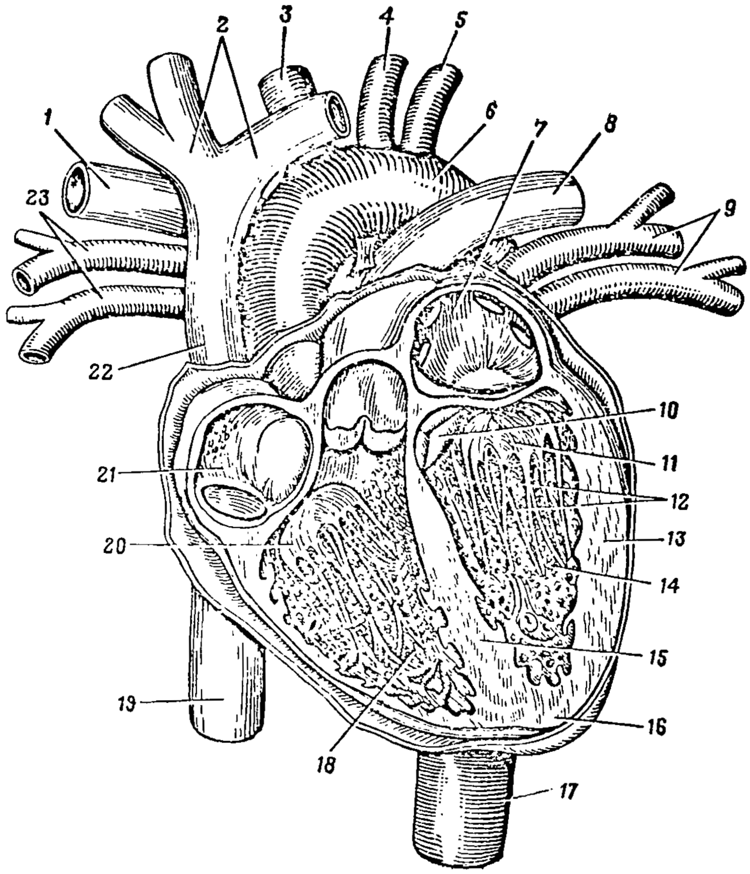

Figure 12. Heart:

1 - right pulmonary artery; 2 - brachicephalic veins; 3 - brachicephalic trunk; 4 - left common carotid artery; 5 - left subclavicular artery; 6 - arch of the aorta; 7 - left auricle; 8 - left pulmonary artery; 9 - pulmonary veins; 10 - valves of the aorta; 11 - mitral valve; 12 - tendinous threads; 13 - muscle layer of the heart; 14 - left ventricle; 15 - cardiac septum; 16 - apex of the heart; 17 - aorta; 18 - right ventricle; 19 - inferior vena cava; 20 - tricuspid valve; 21 - right auricle; 22 - superior vena cava; 23 - right pulmonary veins.

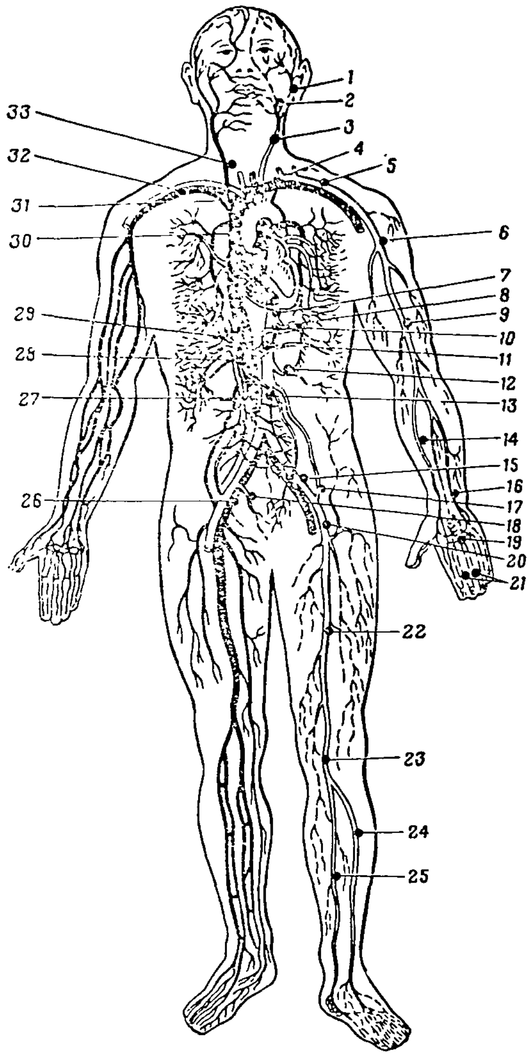

Figure 13. Blood vessels:

1 - superficial temporal artery; 2 - facial artery; 3 - left common carotid artery; 4 - brachiocephalic trunk; 5 - subclavicular artery; 6 - subaxillary artery; 7 - thoracic aorta; 8 - splanchnic trunk; 9 - brachial artery; 10 - splenic artery; 11 - superior mesenteric artery; 12 - inferior mesenteric artery; 13 - abdominal aorta; 14 - radial artery; 15 - external iliac artery; 16 - cubital artery; 17 - internal spermatic or ovarian artery; 18 - internal iliac artery; 19 - palmar arterial arcs; 20 - external iliac artery; 21 - digital arteries; 22 - femoral artery; 23 - popliteal artery; 24 - anterior tibial artery; 25 - posterior tibial artery; 26 - common iliac artery; 27 - inferior vena cava; 28 - vena porta; 29 - vena hepatica; 30 - superior vena cava; 31 - right brachiocephalic vein; 32 - vena subclavia; 33 - vena jugularis interna.

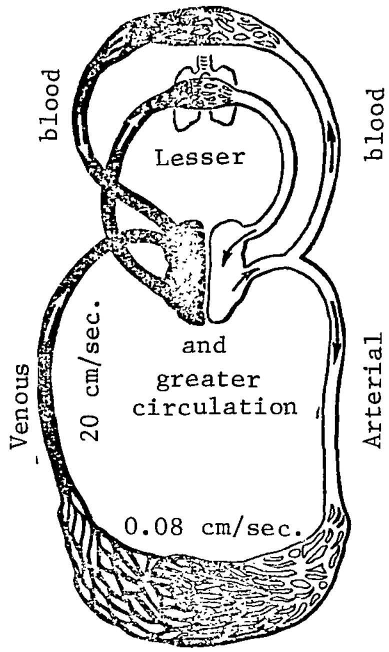

Figure 14. Diagram of the circulation.

begins) into the largest arterial vessel, the aorta, from which it flows along the network of arteries to all tissues and organs of the body. After giving up its oxygen and nutrient substances to the tissues, the blood returns along the veins to the right auricle. This is where the greater circulation ends.

The lesser circulation. From the right auricle (beginning of the circuit) the blood passes into the right ventricle and then into the pulmonary artery. It is divided into branches which split into a great many capillaries, thickly interwoven with the pulmonary alveoli. From the capillaries, the blood first runs through small and then larger veins to the left auricle (end of the circuit). Out of all the arteries, it is only in the pulmonary artery that the blood is not arterial but venous. In the pulmonary veins, however, on the other hand, the blood is arterial.

In the lungs, gas exchange takes place through the walls of the alveoli and capillaries between the blood and the alveoli air. The required rate of movement of the blood through the vessels is maintained by the work of the heart. The heart of an adult contracts on the average 60 to 80 times per minute. The maximum rate of movement of the blood in the aorta is about 0.5 m /58
per second, and in the capillaries — 0.5 mm per second, i.e., 1000 times less. The total length of the capillaries in the human body is 100,000 km.

The volume of blood expelled by the heart in one contraction is called the pulse volume, while that transported in one minute is the minute volume. In the case of a healthy man in a resting position, the pulse volume of each ventricle is equal to 70 cm^3 on the average, while the minute volume is five liters. Consequently, in the course of an hour the heart will contract to propel about 300 liters of blood. As the physical load increases, the heart increases its work: the cardiac contractions become more frequent and the pulse volume of blood increases.

Support-Motor System

The skeleton carries out supporting and protective functions (for the internal organs) and forms the supporting-motor system of man together with the muscles.

The human skeleton (Figure 15) consists of more than 200 bones and is usually divided into the following parts: skull, spinal column, rib cage, pelvis, upper and lower extremities. Each part consists of several bones which are firmly, semi-permanently and movably linked together.

The skull is the bony foundation of the head, made up of 23 bones. There are two principal parts of the skull, the cerebral and facial. The cerebral portion is the bony cavity formed by the frontal, temporal, basal and occipital bones; the facial section is made up of the frontal, superior and inferior maxillaries, the nasal bone and others. The bones of the skull are connected together firmly. The skull protects the brain against external influences (mechanical, temperature, and so on).

The spinal column consists of 33 vertebrae, linked together by cartilage and ligaments which allow the vertebrae a certain amount of flexibility. It fulfills a protective function with respect to the spinal cord and is also the principal support for the trunk, the basis of the skeleton.

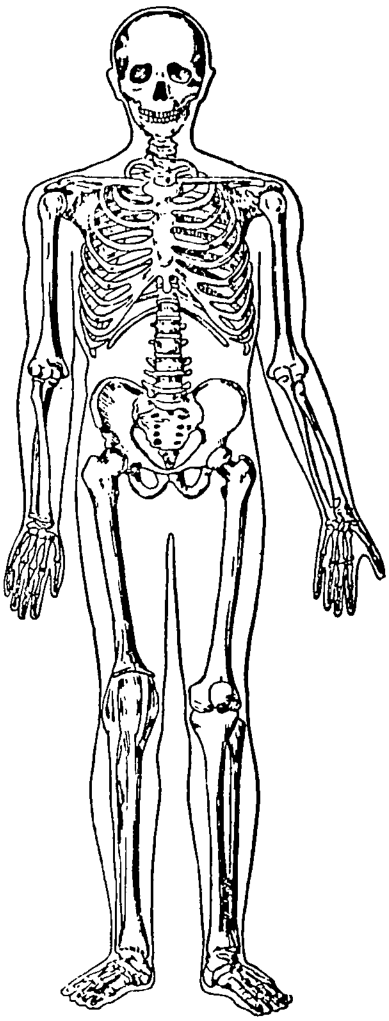

Figure 15. Human skeleton.

The rib cage is formed by the ribs, the chest portion of the spinal column and the sternum. The connections between the bones are movable to /59 a certain extent, which is made possible by the mobility of the entire chest cage and the possibility of carrying out respiratory movements. The rib cage, having a support function, simultaneously protects the heart and lungs against external influences.

The pelvis, composed of several bones, serves as a support for the organs of the abdominal cavity and as a cingulum for the lower extremities. The bones which form the upper and lower extremities are levers of a sort, which are set in motion by the muscles. The bones of the extremities are connected together by movable connections called joints. The majority of joints are surrounded or reinforced by ligaments, which hold the jointed bones in contact and limit their degree of movement. The ligaments possess considerable mechanical strength and a certain degree of elasticity. Ligaments are usually found in the bursae of the joints. The strongest ligaments are found in the coxofemoral, genual, and ulnar joints and in the vertebrae.

Every movement made by a human being is the result of the operation of muscles which are fastened to the bones by means of tendons. When they contract, the muscles perform mechanical work. The source of energy for the contraction of muscles is complex organic substances (proteins, fats and carbohydrates), which are broken down with the necessary participation of oxygen. Oxygen and the required organic substances are brought to the muscles by the blood. /60

The stimulus which causes muscle activity reaches them by way of centrifugal nerves from the central nervous system. In the central nervous system, it arises due to stimulation of the endings of the centripetal nerves which are located in the skin, muscles, tendons and other organs, or the arrival of "primary" central impulses.

Organs of Excretion

The organs of excretion in man include the kidneys, ureters and the lower sections of the intestine. To some extent, the skin and lungs have excretory functions. These organs eliminate from the human organism the final and unnecessary products of metabolism: water, carbon dioxide, salts, urea, etc.

The breakdown products of erythrocytes, bile pigments, are excreted through the intestine, as are calcium, phosphate which is insoluble in water, and certain compounds of iron which are undigested and unassimilated nutrient substances. Through the lungs, carbon dioxide and to some extent water are excreted. Products of decay which are soluble in water are excreted through the kidneys (Figure 16) in the form of urine and through the sweat glands in /62
the skin in the form of perspiration.

The amount of urine excreted by man is not uniform. It depends on the amount of liquid drunk, the nature of the drink, the climate and the physical stress. On the average, the kidneys each day excrete about 1-1/2 liters of

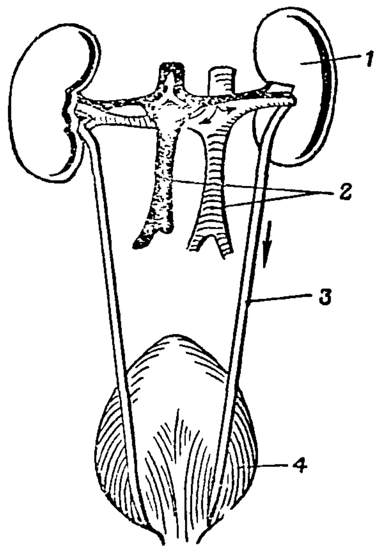

Figure 16. Diagram of excretory organs:

1 - kidney; 2 - aorta and inferior vena cava; 3 - ureter; 4 - urinary bladder.

urine which contains up to 60 g of various salts of organic and inorganic origin. Any disruption of the activity of the kidneys may lead to retention of substances in the blood which are harmful and even dangerous to the organism.

The sweat glands in the skin (Figure 17) are long narrow tubules which are coiled into balls located in the subcutaneous fatty layer. They open in the form of pores on the surface of the skin. These glands are distributed non-uniformly over the surface of the body. The largest numbers of them are in the axillary and inguinal areas and on the palms and feet.

In the course of a day, the sweat glands excrete about 0.4 - 0.6 liter of water and up to 10 g of various substances, primarily salts. During severe muscular work and high temperature of the ambient air, excretion of sweat increases sharply and may reach several liters per hour. Sweating plays an important role in the temperature regulation of the organism with a change in the temperature regime of the surrounding medium. Approximately 600 to 750 g of carbon dioxide and up to 0.4 liters of air are excreted through the lungs in the course of a day from the organism.

Digestive System

The digestive system (Figure 18) includes the following: oral cavity (tongue, teeth, salivary glands, etc.), pharynx, esophagus, stomach, liver and pancreas.

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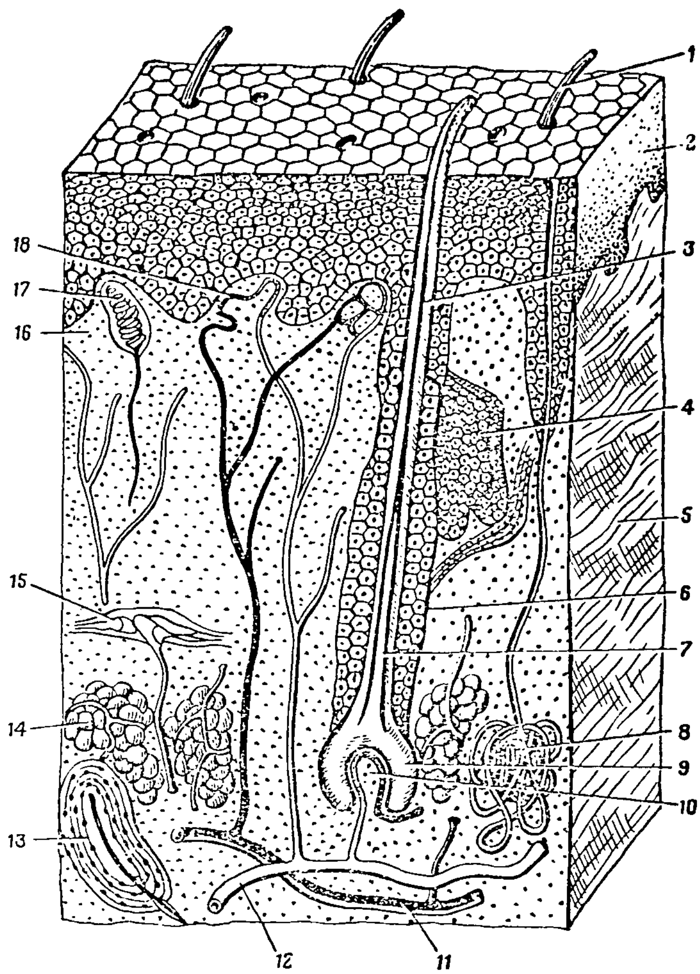

Figure 17. Diagram of skin structure:

1 - hair shaft; 2 - epidermis; 3 - hair; 4 - sebaceous gland; 5 - skin proper; 6 - external radical vagina; 7 - hair root; 8 - sweat gland; 9 - hair bulb; 10 - hair papilla; 11 - cutaneous artery; 12 - cutaneous vein; 13, 15, 17 - nerve endings; 14 - fatty tissue; 16 - growth layer; 18 - capillaries.

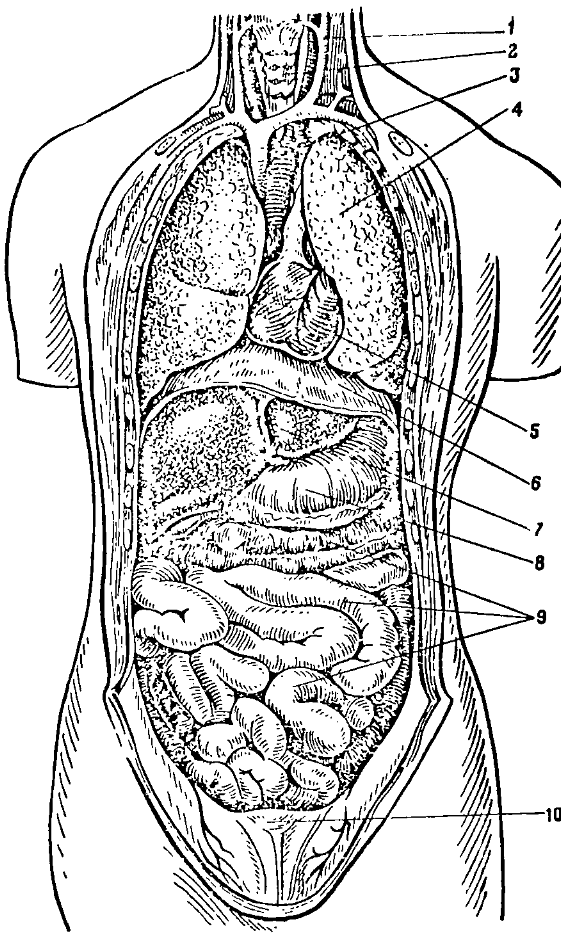

Figure 18. Internal organs:

1 - throat; 2 - trachea; 3 - aorta; 4 - lung;
5 - heart; 6 - diaphragm; 7 - liver; 8 - stomach;
9 - intestine; 10 - urinary bladder.

The food products used by man contain different amounts of nutrient substances — proteins, fats and carbohydrates, as well as mineral salts and vitamins. Nutrient substances are used in the formation of new cells and serve as an energy source for the vital activity of the organism. However, in order that these substances may be used by the cells of the organism, they must be converted in an appropriate fashion; this is done by the digestive /64 organs. In the course of digestion, complex organic products are broken down into simpler ones easily assimilated by the cells.

In the digestive tract, two processes take place: (1) physical and chemical changes in the food — digestion; (2) absorption of the products of this breaking up, formed as a result of these changes.

The physical changes in the food consist in the grinding up and solution of its component parts, while the chemical changes involve breaking down complex substances into simple ones. Proteins are broken down into amino acids, fats into glycerine and fatty acids, and carbohydrates (sugar, starch) are broken down into simpler sugars — glucose, fructose, galactose and so on.

The entire complicated process of digestion takes place under the influence of so-called enzymes, which accelerate the chemical reactions in the organism many fold.

The process of absorption is the process of getting the final products of breakdown of nutrient substances into the blood. The blood carries them all through the entire organism, whose cells absorb the substances they require. The undigested portions of the food pass into the small intestine and then into the large intestine and then are excreted from the organism.

The processes of digestion and absorption involve a considerable increase in the intensity of the work of all organs in the digestive system and are accompanied by an increased use of oxygen. Therefore, the blood supply to the organs and systems which are not involved in digestion, including the central nervous system, decreases at this time.

CHAPTER IV

INFLUENCE OF HIGH-ALTITUDE FLIGHT ON THE HUMAN ORGANISM

High-Altitude Flights and Oxygen Starvation

High-altitude flights are one of the most complicated forms of activity performed by the members of the Air Force and impose considerable nervous, /65 emotional and physical stresses.

High-altitude flights are those which are carried out above 4,000 m. At these altitudes, the partial pressure of oxygen in the atmospheric air decreases and becomes insufficient for maintenance of normal vital activity of the organism. In addition, during a high-altitude flight, the individual may be subjected to the unfavorable influence of reduced barometric pressure and sharp drops in the latter, low air temperature, change in the conditions of visual orientation as well as more intensive radiation.

Ensuring the safety of high-altitude flights involves solving many complicated medical problems, especially the problems of protecting the individual against the unfavorable influence of reduced atmospheric pressure and the related factor of oxygen starvation of the organism.

Oxygen starvation may occur in case of an emergency in flight, for example, in case of cabin decompression at high altitudes, damage, failure or incorrect operation of onboard oxygen apparatus.

The pilot must know the reasons, the nature of the occurrence and the /66 possible consequences of oxygen starvation, and must also be familiar with the methods and means of preventing it.

The influence of oxygen starvation on the human organism is studied primarily in barochambers and in flights. The study of the influence of reduced barometric pressure on the human organism began with ascents made on high mountains. The unusual painful state which occurs in man when he ascends to high mountains was called "mountain sickness". It is usually accompanied by muscular weakness, exhaustion, headache, dizziness, fatigue, nasal hemorrhaging, and loss of consciousness.

With the development of aeronautics and aviation, flight altitude nnd rate of climb increased rapidly. It was found that phenomena were observed on board a balloon or an aircraft as it gained altitude that were reminiscent of mountain sickness.

During exposure of man to reduced barometric pressure, a number of disruptions to functions of individual organs and the organism as a whole take place. The principal role in this regard is not played by the reduced barometric pressure of the air, but by the reduced partial pressure of oxygen in the inspired air.

With normal atmospheric pressure (760 mm Hg), which corresponds to a partial pressure of oxygen of 159 mm Hg in the capillaries of their lungs, healthy individuals will have blood which is saturated to a sufficient degree with oxygen and which reaches their tissues in the required amounts. While at sea level the saturation of the blood with oxygen reaches 96 - 98%, at altitudes of 3,000, 4,000, 5,000 and 6,000 m the value is 90, 85, 80 and 75%, respectively.

The degree of saturation of the blood with oxygen depends on the partial pressure of the oxygen in the alveolar air: the higher it is, the better and more completely the process of saturation proceeds. The partial pressure of the oxygen in the alveolar air increases with an increase in its partial pressure in the atmosphere.

TABLE 6

Altitude, m	Barometric Pressure, mm Hg	Partial Pressure of O_2, mm Hg in inspired air	Partial Pressure of O_2, mm Hg in alveolar air
0	760	159	103
1 000	674,12	141	90
2 000	596,28	125	79
3 000	525,98	110	69
4 000	462,46	98	60
5 000	405,37	85	52
6 000	354,13	74	44
7 000	308,26	64	38
8 000	267,38	56	32
9 000	230,95	48	26
10 000	198,70	41	22
11 000	170,19	36	18
12 000	145,44	30	14
13 000	124,30	26	11
14 000	106,24	22	8
15 000	90,81	19	6
16 000	77,616	16	3
17 000	66,350	14	0
18 000	56,719	12	—
19 000	48,489	10	—
20 000	41,455	8,7	—
21 000	35,443	7,4	—
22 000	30,305	6,3	—
23 000	25,912	5,4	—
24 000	22,158	4,6	—
25 000	18,948	3,9	—
26 000	16,219	3,4	—
27 000	13,910	2,9	—
28 000	11,959	2,5	—
29 000	10,295	2,2	—
30 000	8,878	1,9	—

Data on the change in the total barometric pressure as well as the partial pressure of oxygen in the atmosphere (inspired air) and alveolar air with a gain in altitude are shown in Table 6.

Sensitivity of various organisms and tissues of the organism to a lack of oxygen is different. For example, the bony and cartilaginous tissue, as well as smooth muscles, can retain their vital activities for a long period of time with significant oxygen insufficiency. The maximum sensitivity in this regard is displayed by the central nervous system, especially the cerebral cortex and the cerebellum. Within 2 - 3 min following total interruption of the oxygen supply to the cerebral cortex, irreversible changes take place and the cells die. /68

The degree of oxygen starvation depends on the height of ascent, time spent at the high altitude, and the condition and individual characteristics of the organism. In elderly and sick people, oxygen starvation begins at lower altitudes than for young people and healthy ones.

Altitude Sickness

The concept of "altitude sickness" combines a number of functional defects in the organism, especially in the central nervous system, which occur under conditions of oxygen starvation.

Characteristic features of altitude sickness are the following: initially there is an excited state and an uplifting of spirits, followed by a feeling of warmth in the face and a flow of blood to the head, dyspnea, headache, nausea, weakness, somnolence, indifference to surrounding events, disruption of attention, slowing down of response reactions to external stimuli, difficulty in carrying out counting operations, decrease in working ability, disruption of fine coordinated movements and handwriting (Figure 19), a feeling of cold in the extremities, paleness or blueness of the cutaneous coverings, dizziness, nausea, and sometimes vomiting. In serious cases,

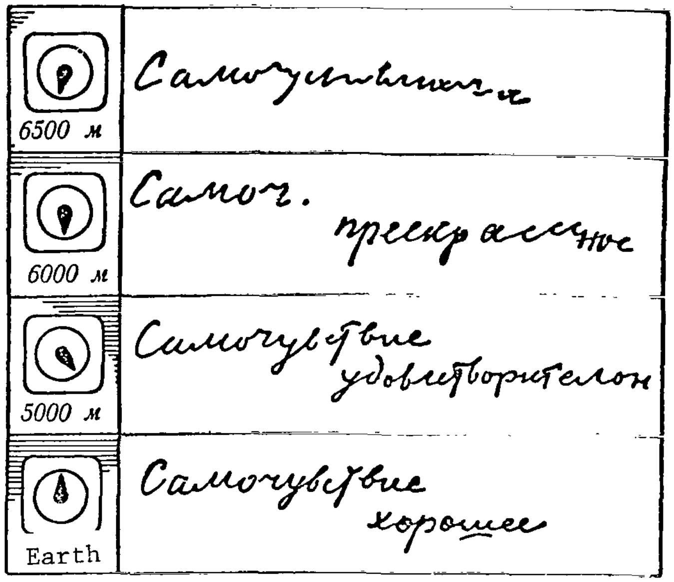

Figure 19. Change in handwriting with altitude.

loss of consciousness occurs, and if measures are not taken deєth may ensue from paralysis of the respiratory center.

If an individual making an ascent does not use oxygen apparatus or for some reason the supply of oxygen is cut off, the first signs of altitude sickness sometimes appear as early as 2500 - 3000 m. At 4000 - 4500 m, these symptoms become quite pronounced in most people. As indicated by experience with "ascents" in a barochamber, a stay at an altitude of 5000 m and respiration for the first 30 minutes of atmospheric air in certain healthy persons /69
may cause the development of altitude sickness in a serious form, making it necessary to "descend" to a lower altitude or to stop the test. At an altitude of 6000 m, an altitude sickness in this form develops much more frequently and becomes dangerous for life. At 7000 - 7500 m, the majority of people,

even after only six to seven minutes, may suffer loss of consciousness. At high altitudes, the rate of development and seriousness of occurrence of altitude sickness increase. Thus, for example, at 11,000 to 12,000 m, serious consequences and loss of consciousness occur on the average in 25 - 40 seconds. At 15,000 - 16,000 m, even when oxygen is being breathed, altitude sickness develops very sharply and rapidly due to the generally low pressure, and loss of consciousness occurs in 10 to 15 seconds.

Manifestations of altitude sickness, as well as its symptoms, are /70 encountered in highly diverse combinations at the same altitude not only in different persons, but in the same individual. The individual characteristics of the organism which determine its altitude resistance show up clearly only up to altitudes of 7,000 m. These differences become less distinct as the altitude increases, and by 10,000 to 12,000 m altitude sickness develops practically the same in everyone as far as the time of its occurrence and the seriousness of the symptoms is concerned.

Altitude sickness follows one law: the greater the altitude, the more rapidly and severely it develops.

The principal danger of altitude sickness lies in the fact that the flow of psychic processes is interrupted first of all. The individual cannot evaluate his own condition and the surrounding situation in a healthy and critical manner. An insidious aspect of altitude sickness is the fact that there are frequent cases of a rapid transition from mild cases to more serious ones. Sometimes, even against a background of complete well-being, without any warning, serious symptoms of altitude sickness can develop and result in sudden loss of consciousness.

Altitude sickness arises most frequently as a result of failure or incorrect operation of on-board oxygen respiration apparatus and in the event of failure of cabin pressure in an aircraft during flight at high altitude. Each of these cases is considered an extraordinary event.

As studies have shown, altitude resistance of the organism depends on many factors in the external and internal medium. An unfavorable effect on altitude resistance is produced by overcooling or overheating of the organism immediately before flight and especially during flight, not getting enough sleep, overfatigue, simple stress, flying on an empty stomach or immediately after eating a large meal, an unhealthy state, serious emotional disturbances, residual phenomena following alcoholic intoxication as well as the use of alcohol before flight, excessive smoking, poisoning by exhaust gas, kerosene vapors, gasoline and the products of pyrolysis of lubricants.

Airsickness /71

In aviation practice, so-called airsickness (resembling seasickness) is encountered as well as altitude sickness. Its development is not directly linked to oxygen starvation, although the latter may accelerate the development and make the course of this disease more serious.

Airsickness develops in certain pilots during flight in a rough atmosphere, i.e., in the presence of powerful rising and descending air currents — rough air. Most often this disease appears as a result of the individual being affected by angular accelerations during piloting. These accelerations cause specific stimulation of the vestibular apparatus which accumulate and produce a reaction by the nervous system which takes the form (in a final analysis) of nausea, vomiting, paleness of the skin, cold sweat and dizziness. Sometimes the result of this reaction is a feeling of fatigue, headache, mental confusion, etc.

The ordinary clinical picture of air sickness involves stimulation not only of the vestibular apparatus but also of numerous sensitive nerve endings which are located in the inner organs and tissues of the organism. Nerve impulses arriving from these receptors in the central nervous systems make the effect of this disease still more serious.

It is interesting to note that pilots, when flying as passengers, are affected more frequently than when they themselves are piloting an aircraft. Apparently, when the pilot is at the controls himself, the stress from the nervo-psychic sphere is of significant importance, inhibiting the formation of vestibular reflexes.

Airsickness is similar to the familiar seasickness: the same mechanisms form the basis of both. However, seasickness usually occurs in a more pronounced form and in a greater number of people. This is explained by the fact that the specific stimulant at sea (rolling) as a rule acts for a longer period of time than in the air.

We know that people withstand the rolling of a ship in different ways: some better than others. Those who cannot withstand the rolling of a ship respond poorly to vestibular training. Therefore, the principal preventive /72 measure for airsickness in the air force is a careful medical check of all candidates for flight schools. In civil aviation, several medical preparations are available for preventing airsickness in passengers, containing such substances as scopolamine, atropine, belladonna, etc.

Influence of Oxygen Starvation on the Central Nervous System

The teachings of I. P. Pavlov regarding the higher nervous activity and the physiology of the brain have formed the basis of research on the influence of oxygen insufficiency on the central nervous system. According to this theory, the cerebral cortex is the supreme organ which regulates and coordinates all vital functions of the organism. Impulses traveling from it direct and correct the course of highly diverse processes in the organism, including intracellular processes. I. P. Pavlov wrote that the highest section of the central nervous system controls all events taking place in the body.

Disruption of the activity of the cerebral cortex, caused by oxygen starvation, is immediately reflected in the functions of the lower sections of the brain and also in the activity of the internal organs. In the event of any change at all in the state of the internal organs, impulses which affect the activity of the cortex reach the central nervous system.

Any degree of oxygen starvation caused by a drop in partial pressure of oxygen in the inspired air and by other causes leads to changes and, in many cases, to disruption of the activity of the central nervous system. An unfavorable influence on the central nervous system during oxygen starvation is also produced by a lack of carbon dioxide in the tissues of the organism, which is formed as the result of an increase in ventilation of the lungs.

The high sensitivity of the cells of the central nervous system to a shortage of oxygen is explained by the fact that the nerve cells, like the cells of other tissues, do not have their own reserves of oxygen even though their need for it is many times greater than that of other cells. Suffice it to say that 20% of the oxygen reaching the human organism is absorbed precisely /73 by the brain, although its weight constitutes only 2% of the total body weight.

As experiments have shown, the sensitivity of nerve cells to oxygen insufficiency is highest in man. The nerve cells of various parts of the central nervous system react differently to oxygen insufficiency; their resistance decreases as we move from the lower sections to the higher ones. The cells of the cerebral cortex are most sensitive and least resistant to oxygen insufficiency.

The influence of oxygen starvation is manifested by degeneration of the central nervous system activity, primarily in the cerebral cortex. It is primarily the complex psychic and conditioned-reflex activity which is most seriously affected. The nature of these disruptions and the rate of their development are in direct proportion to the degree of oxygen starvation, individual characteristics of the organism and also its physical and neuro-emotional state at a given moment. At high levels of oxygen starvation, the central nervous system shows very pronounced disorders which may cause the death of the individual.

The appearance of functional disorders in the central nervous system under conditions of oxygen starvation is complex and differs not only in different persons, but even in the same person. In order to get a clearer picture of these disruptions, it would be advantageous to know the most typical signs of these changes. There are two phases in the behavior and general state of an individual, caused by the influence of oxygen starvation on the central nervous system: the phase of excitation and the phase of depression.

The phase of excitation usually occurs at altitudes of 2,500 to 3,000 m and is characterized by liveliness of behavior, increased talkativeness and good humor, acceleration of the course of psychic reactions, a tendency toward active movement. However, the quality of the work deteriorates, there is frequently a drop in the capacity for critical evaluation of the individual's own condition, as well as his actions, and the surrounding conditions. The state at this phase may be compared to one of mild alcoholic intoxication.

This phase is characterized by the individual overrating his abilities: /74
he is convinced that his state is normal, and that his actions are correct; he may already be on the brink of loss of consciousness, though his actions do not reflect the situation.

The phase of depression begins at an altitude of 4,000 m. It is characterized by a decrease in the working ability of the individual. At this phase, his observing ability and capacity for judgment decrease, the scope of his attention narrows, his memory grows weak, the observation of instruments becomes more difficult, his ability to carry out simple mathematical calculations deteriorates, and visual estimation is disturbed. As time passes, the state of the individual may become still worse: he can be sluggish, weak, apathetic, sleepy, show a sharp slowing down in the rate of mental activity, forgetfulness, numerous errors in calculations and writing, skipping or misspelling individual letters and words, repetition of individual words and phrases, disruption of fine coordinated movements and handwriting. Finally, he may suffer mental confusion and faint.

If the degree of oxygen starvation does not increase (flight at the same altitude) a periodic shift of the brief phase of excitation to the long phase of depression may be seen.

Practice has shown that sudden loss of consciousness occurs only in the case of a very rapid climb to an altitude above 5,000 m or in the case of sudden loss of oxygen, at great height. In certain cases, loss of consciousness may occur against a background of apparently perfectly normal behavior. The pilot may then be unable to detect the moment at which the fainting begins to develop.

Influence of Oxygen Starvation on the Function of the Analyzers

Disruption of the activity of the cerebral cortex under conditions of oxygen starvation at high altitudes shows up comparatively early in the functions of the analyzers.

The visual analyzer is most sensitive to oxygen starvation. It is important to note that it is the principal functions of the visual analyzer which are affected, and which are very important to the pilot (for example) for observing and recognizing objects on the ground as well as targets in the air, reading his flight charts, noting the readings of the instruments, etc. These functions include: color and contrast sensitivity, color vision, visual /75
acuity, depth of vision and ability to accommodate.

Light sensitivity of the eye decreases even at heights of 2,000 - 3,000 m, while in some cases even at a height of 1,500 m. At an altitude of 4,500 to

5,000 m, this decrease becomes significant, particularly in people with insufficient resistance to oxygen starvation as well as under considerable physical stresses. In the case of functional disorders of the cardiovascular activity, light sensitivity deteriorates at lower altitudes and is more pronounced.

The contrast sensitivity of the eye is the ability to detect the smallest differences in brightness between the object and the background; this decreases beginning at 5,000 m. As the oxygen insufficiency becomes more acute, this ability continues to deteriorate and at 7,000 m it falls by 50% on the average.

Color vision begins to show disturbances at 1,500 m; a further climb makes this disturbance more serious. Beginning at 4,500 m, there is deterioration of the ability to detect color saturation, while at altitudes of 5,000 - 6,000 m it is difficult to distinguish color. At these altitudes, white appears as yellowish gray, and black appears as gray. Detection of green and blue deteriorates most sharply. At altitudes of 6,000 m and up, the ability to distinguish blue from green disappears entirely. In order to distinguish other colors from this altitude, it is necessary that they be more saturated.

Visual acuity up to altitudes of 4,500 - 5,000 m changes insignificantly if the objects are well lit. However, in the case of low illumination, it deteriorates to a degree which is more serious as the degree of oxygen starvation becomes more acute and the objects are more poorly illuminated. During the daytime, visual acuity deteriorates noticeably beginning at 6,000 m.

The initial phenomena indicating a narrowing of the field of vision are observed at 4,500 m; by 6,000 m this restriction is very markedly apparent.

Depth or spatial vision in some people changes significantly even at 3,000 m, while at 5,000 m and up it is seen in everyone. The nature of this /76
disruption depends directly on the degree of oxygen insufficiency and the resistance of the organism to it. The direct cause of the change in depth

perception is the weakening of the tone and disruption of equilibrium of the optic muscles, caused by deterioration of the coordinated functions of the central nervous system.

A drop in the ability of the eye to accommodate (characterized by the magnitude of the distance from the eye of the observer to the point of nearest vision) is observed beginning at 5,000 m. Under conditions of oxygen starvation, the time required for normal visual perception of the surroundings increases. Consequently, some objects (phenomena) which act on the retina of the eye for a short period of time may not be detected.

A shortage of oxygen also has an unfavorable effect on the retina of the eye itself. Comparatively rapid recovery of the visual ability of the eye during a transition to breathing pure oxygen indicates that under the influence of oxygen starvation the disruptions of the visual analyzer have a functional nature, are reversible, and do not cause serious organic damage.

All of the measures that are involved in increasing the altitude resistance of the organism have a positive influence on the recovery of the functions of the visual apparatus. Among the measures that have been especially developed for increasing visual functions, one of the most important is the use of the vitamin A, B and C complex.

The auditory analyzer is much less affected by oxygen starvation. Studies indicate that hearing acuity decreases only at altitudes about 5,500 m and may remain depressed for some time after landing. The reason for deterioration of hearing at great heights is the fact that the same thing is affected as in the case of the visual analyzer — disruption of the activity of the cerebral cortex.

The functions of the vestibular analyzer are disturbed only with a marked degree of oxygen starvation. In the course of experiments with rolling, conducted on special stands, it was established under conditions of pronounced oxygen insufficiency that this disturbance is observed somewhat more frequently than when normal atmospheric air is breathed (at a pressure of 760 mm Hg). /77

Pain and tactile sensitivity begin to increase at altitudes of 2,000 - 5,000 m, and decrease with a rise in oxygen insufficiency and increasing altitude per length of time spent at these altitudes. The temperature sensitivity also decreases.

The sense of taste and smell are affected beginning at 4,500 - 5,000 m. It should be pointed out that acidified beverages appear to be most pleasant for quenching thirst at high altitudes. With a properly sealed cabin and normal operation of the oxygen equipment, the possibility of development of oxygen starvation is excluded, and so is disruption of the function of the analyzers.

Effect of Oxygen Starvation on the Respiratory System

The most important effect on the respiratory system is caused not by a rarefaction of atmospheric air, but by a drop in the partial pressure of oxygen in the inspired air.

Under conditions of oxygen insufficiency, there are changes in the external and tissue respiration and the pulmonary gas exchange. The change in respiration under conditions of moderate oxygen starvation are accompanied by adaptive reactions; however, at severe levels of oxygen starvation, reactions of a compensatory nature develop, which in the final analysis may be inadequate, which makes the disturbance of other important functions of the organism more serious.

A fixed characteristic of the reactions of the respiratory system to oxygen insufficiency is the increase in pulmonary ventilation accompanied by a speeding up of the rhythm and an increase in the depth of respiration. A slight increase in pulmonary ventilation in man may already be observed at

1,000 m, while at 2,500 m it is clearly evident. Pulmonary ventilation increases to different degrees in different persons under the same conditions. In some individuals, it may increase by a factor of 2. In general, however, the increase in pulmonary ventilation (when the individual is in a state of rest) depends on the altitude and rate of climb; the greater they are, i.e., the more rapidly the partial pressure of oxygen falls, the more important is the increase in the pulmonary ventilation. It increases particularly sharply in the event of physical stress caused by increased demands on the organism for oxygen. Under conditions of oxygen starvation, with a certain physical stress, pulmonary ventilation increases more significantly than with the same stress under conditons of normal oxygen supply. /78

With an increase in pulmonary ventilation with altitude, there is a rise in the partial pressure of oxygen in the alveolar air, and consequently the saturation of the blood with oxygen increases. Under these conditions, there is an enormous positive significance of the increase in ventilation of the lungs. However, unnecessary increased ventilation may have a negative influence and cause severe "washing out" of carbon dioxide from the organism, which stimulates the activity of the respiratory center and also speeds up the saturation of the blood in the lungs with oxygen and its transition from the blood to their tissues of the organism.

When a change is made to breathing oxygen, pulmonary ventilation returns to normal in 1 - 2 minutes.

In the case of pronounced oxygen starvation, there is finally a breakdown of respiration. It becomes irregular, frequent, shallow; pulmonary ventilation decreases sharply, which can soon lead to a loss of consciousness. However, there are frequent cases of loss of consciousness where the increase of pulmonary ventilation and the speeding up of respiration were only slightly evident. Disruption of respiration in the case of severe oxygen starvation develops as a result of inhibition of the respiratory center in the cerebral cortex.

Influence of Oxygen Starvation on the Circulatory System

The main factor influencing the activity of the circulatory system during oxygen starvation is also the decrease in partial pressure of oxygen in the inspired air.

Experiments in barochambers as well as observations made during high altitude flights indicate that, if there is an artificial increase in the partial pressure of oxygen in the alveolar air to terrestrial values (105 mm Hg), the circulatory system will not be subjected to reactions that involve stays at a high altitude without additional oxygen supply. On the other hand, /79
these reactions show up clearly even under conditions of normal atmospheric pressure when breathing gas mixtures that contain less oxygen than is found in atmospheric air at sea level.

One of the earliest and clearest indicators of changes in the activity of the cardiovascular system under conditions of oxygen insufficiency is the change in the pulse rate (speeding up). This is the clearest indicator of the reaction of the circulatory system to altitude. In some persons, the speeding up of the pulse begins at an altitude of 1,000 - 1,500 m. Usually, this speeding up becomes more significant as altitude grows greater, but considerable individual differences are also seen.

With a slow climb and prolonged stay at a certain altitude, an individual may become accustomed to the conditions of the medium. This means that, regardless of a certain relative decrease in pulse rate (in comparison to the rate during the first period at this altitude), it still remains faster than on earth. Usually, a significant speeding up of the pulse is noted in the case of physical stress, which as we have already pointed out, has to do with the greater demand of the organism for oxygen.

The arterial blood pressure during oxygen starvation increases somewhat in most people. As a result of the speeding up of the heart contractions, the blood makes a full circuit more rapidly, considerably increasing the rate at which oxygen is supplied to the tissues. At the same time that the pulse speeds up and the blood pressure rises, there is also an increase in the minute volume of blood pumped by the heart into the blood vessels. Consequently, the supply of oxygen to the tissues is improved, since more blood passes through the tissue capillaries per unit time.

When the action of the neuroreflex mechanisms is activated, there is an increase in the mass of circulating blood, primarily in the red blood cells (erythrocytes). This is achieved by mobilization of the "blood deposit"; i.e., blood which is deposited (contained in reserves) in the spleen and liver. This results in an increase in the total respiratory surface of the erythrocytes and the amount of hemoglobin, which transports the oxygen in the circulating blood. If there is a threat of a drop in oxygen pressure in the /80
cerebral vessels, a redistribution of the mass of circulating blood is accomplished by reflex, so that the blood supply to the organs most important for life is increased (central nervous system, heart and lungs) at the cost of reducing the blood supply to the muscles, skin and other organs which have high resistance to oxygen insufficiency.

Hence, the circulatory system manifests a number of reactions under the conditions of oxygen insufficiency which are aimed at insuring that the organism receives the necessary supply of oxygen. However, the changes described above for the activity of the cardiovascular system are characteristic for moderate levels of oxygen starvation. At severe degrees of oxygen starvation (at 6,000 - 7,000 m) the reserve capability of the apparatus for circulation becomes insufficient and is rapidly exhausted. The pulse either speeds up tremendously or becomes very slow, and the rhythm breaks down. This sign is a precursor of unconsciousness.

The condition of the circulation is also affected by low temperature. Under the influence of cold, there is a reinforcement of metabolism which requires additional expenditure of oxygen and increases the load on the cardiovascular and respiratory systems.

Influence of Oxygen Starvation on Metabolism

Participation of oxygen in interrelated biochemical oxidation processes is of primary importance for vital activity.

Studies have shown that changes in metabolism in the organism of man under conditions of oxygen deficiency are very diverse and complex.

The dependence of the change in the metabolism on the degree of oxygen starvation may be characterized by a weakening of the oxidation processes in the organism and an accumulation of unoxidized products in the tissues, as well as a disruption of the regulating influence of the central nervous system and the endocrine glands on the metabolism due to an attenuation of biochemical processes in the cells of these organs.

The nature and severity of metabolic disorders depend upon the degree of oxygen starvation, the level of physical stress, the state of the neuro-psychic sphere, the air temperature, individual functional characteristics of the organism and the degree of its training.

Thanks to the highly adaptive abilities of organisms, reacting even to a minimum shortage of oxygen, the physiological and biochemical reserves are immobilized. One of the most extensive reserves is the intensification of the activity of the respiratory and circulatory organs, resulting in an increase in the supply of oxygen to the tissues of the organism.

However, under conditions of oxygen starvation, some forms of metabolism may be changed to varying degrees.

Changes in the protein metabolism under conditions of oxygen insufficiency include incomplete oxidation of proteins, which results in the organism accumulating unoxidized biologically active products of protein origin (histamine, guanidine, acetone bodies), formed from certain amino acids taken in with the food. As the content of these products in the blood increases, there is a deterioration of the general condition of the organism and the ability to withstand oxygen starvation.

In the event of a shortage of oxygen in the organism, there is a disrup- /81
tion of protein synthesis from amino acids and, consequently, a drop in the activity of certain enzymes which participate in biochemical reactions of the organism and in digestive processes. Disturbances of protein metabolism are observed most noticeably in individuals who have had little altitude training.

Changes in fat metabolism under conditions of oxygen starvation lead to a certain disruption of the oxidation of fatty acids, so that undigested products can accumulate in the organism in the form of acetone bodies, acetoacetic, and beta-hydroxybutyric acid. As we have already pointed out, acetone bodies may be formed due to the incomplete oxidation of proteins. In order to oxidize acetone bodies to their end product, it is necessary to have
sufficient carbohydrate in the organism. Acetone bodies are formed and stored /82
in the organism in significant amounts only when the supplies of carbohydrates are completely exhausted and the principal source of energy required for vital activity of the organism becomes fat and proteins.

Carbohydrate metabolism is affected to a lesser degree during oxygen insufficiency than are the other forms of metabolism, since a relatively small amount of oxygen is required for oxidation of carbohydrates. However, during the process of carbohydrate metabolism during oxygen starvation, unoxidized products are accumulated in the form of organic acids (galactic, pyroracemic, citric and others). These acids are accumulated more intensively during physical stress. The normal course of carbohydrate metabolism depends to a large degree upon the content of vitamins from the B group in the organism as well as the amount of vitamin C. Vitamin B_1 forms part of the enzyme which makes possible the breaking down of pyroracemic acid. If there is not enough of it, the sequence of the process of breaking down carbohydrates is disturbed. This process ends with the phase of pyroracemic acid which is stored in the tissues in large amounts. This acid is an intermediate link of protein and fat metabolism. Consequently, the insufficiency or absence of vitamin B_1 may cause a disturbance of these types of metabolism.

Under conditions of oxygen starvation, the consumption of carbohydrates in various organs in the human body is not uniform. The heart muscle and central nervous system place the greatest demands on carbohydrates.

Vitamin metabolism is largely disturbed during oxygen starvation, not only because of lack of oxygen, but also due to the high nervous and emotional stress and the effect of high accelerations. It has been determined experimentally that, under the influence of these flight factors, the requirement of the organism for vitamins A, B_1, B_2, B_6, B_9, P, PP and C increases markedly. Therefore, using complexes of vitamins in the food ration for the pilot increases the resistance of the organism to oxygen starvation and acceleration, improves his working ability and metabolism, and normalizes the oxidation processes in the tissues.

Water and mineral metabolism under conditions of reduced partial oxygen pressure also undergo certain changes. Metabolism of this kind is very closely related to the metabolism of other substances. We know that an accumulation of /83 the salts of potassium, sodium and other elements in the organism involves the metabolism of carbohydrates. When muscles work, potassium is secreted from them and sodium is accumulated. Under conditions of oxygen starvation, there is an increase in the activity of the heart muscle and the muscles of the organs of respiration, so there is a corresponding increase in the content of potassium in the blood and eventually there is an increase in potassium excretion from the organism together with the urine. On the other hand, the excretion of sodium from the organism decreases.

An important role in the metabolism of substances in the organism is played by phosphorus, since a great many of the metabolic processes pass through a stage of phosphorus compounds. Under the conditions of oxygen starvation, the process of conversion of phosphorus compounds is retarded, so that the organism may suffer a shortage of energy reserves. At reduced barometric pressure, there is an increase in water loss by the organism (essentially due to a decrease of it in the tissues), which may reach 1-1.5 kg. The principal causes of an increase in water loss are rarefaction of atmospheric air, dryness of the air and high cabin temperature, considerable nervous and emotional stress and the breathing of dry oxygen.

The water is excreted from the organism as a result of increased evaporation from the cutaneous coverings and the mucous membranes of the upper respiratory tracts and an increase in pulmonary ventilation. In this regard, it is necessary on long flights to provide the crew members with water and pay special attention to their drinking schedule.

Changes in digestion during oxygen starvation appear to most people at an altitude of 4,000 m. There is an inhibition of the activity of the salivary and digestive glands, which takes the form of a reduction of the amount of saliva which is secreted as well as a drop in the amount of gastric juice. Qualitative changes in gastric juice lead to an increase in its acidity. Secretion of juice by the intestinal glands only changes with a significant oxygen deficiency.

The motor function of the digestive organs and the related movement of the food through the gastrointestinal tract in human beings slows down beginning at an altitude of 4,250-4,500 m. The biligenic function of the liver, as has been established by animal experiments, is retarded only during a pro- /84
longed stay under conditions of severe oxygen starvation.

The assimilation of basic food substances changes slightly.

The disruption of juice secretion by the digestive glands and the motor function of the stomach may sometimes be accompanied by an inversion of taste, loss of appetite, fatigue and nausea. Usually those functions of the gastro-intestional tract are affected which are under the direct control of the central nervous system.

Altitude training produces a relative normalization of digestion under conditions of oxygen starvation.

* * *

For the sake of convenience, we can arrange in a vertical pattern several zones and altitudes with most typical pictures of oxygen starvation occurrence (without additional oxygen supply).

The indifferent zone is the lowest layer of the atmosphere (up to an altitude of 2,000 m above sea level), in which no noticeable changes are observed in the reactions of the organism and the feelings of the pilot.

Beginning at an altitude of 2,000 m, changes appear in the sensations felt by the pilot. This altitude is called the reaction threshold. With further climbing to an altitude of 3,000 m, an increase of the activity of the circulatory and respiratory systems in the organism is observed. Due to the compensatory reactions of respiration and circulation, the organism can cope rather well up to this altitude with a shortage of oxygen, and the working ability of the pilot does not decrease for a period of about 3 hours. The interval between altitudes 2,000 and 3,000 m is called the zone of complete compensation.

When the flight lasts more than 4 to 5 hours at an altitude of 3,000 m, a noticeable decrease in the working ability of crew members can be seen.

If the aircraft continues to climb without an additional oxygen supply being provided, the number of phenomena characterizing altitude sickness will increase and the reserve mechanisms of the organism will be unable to insure its complete acquisition of the required amount of oxygen; the changes described above involving the activity of the cerebral cortex, respiratory organs, circulation, etc., will begin to make themselves evident. The beginning of these changes usually can be seen at an altitude of about 4,000 meters. This altitude has come to be called the disturbance threshold. /85

Beginning at an altitude of 4,000 m, we have the zone of incomplete compensation. With further climbing, oxygen starvation has more and more of an effect, altitude sickness develops rapidly, and the disruption of the functions of the organism becomes more serious. The altitude of 6,000 m is considered to be the critical threshold beyond which the so-called critical zone begins. Staying in this zone without additional oxygen supply is dangerous to human life.

A still greater danger is posed by flying without additional oxygen supplies at altitudes of 8,000 m or more. At such altitudes, disruption of the functions of the organism and loss of consciousness occur very rapidly, and the possibility of severe changes developing in the organism which threaten life is created.

This arbitrary division of altitudes into zones corresponds to a certain rate of climb: 1,000 m in 3 minutes. With a faster rate of climb, the limits of the zones change significantly. This division does not take into account individual characteristics of the organism.

The duration of working ability of great altitudes with respiration of atmospheric air or pure oxygen without increased pressure until significant changes occur is called reserve time.

Reserve time essentially depends on altitude (Table 7) and rate of climb (i.e., the rate of which oxygen starvation develops and the individual characteristics of the organism, related to the physical and altitude trainability). Usually, physically strong individuals and persons who have

TABLE 7.

Altitude, m		Reserve Time
6,000	Breathing atmospheric air	10 - 15 min
7,000		6 - 7 min
8,000		2.5 min
9,000		1.5 min
10,000		50 sec
11,000		40 sec
12,000		25 sec
13,000	Breathing pure O_2*	6 min and more
13,500		6 min
14,000		50 sec
14,500		30 sec
15,000		19 sec
15,500		17 sec
16,000 and more		10 - 15 sec

*"Pulmonary Automatic" oxygen apparatus used without increased pressure.

had sufficient altitude training have a somewhat longer reserve time than those who are physically weak or have had little altitude training.

As we can see from Table 7, at great altitudes the reserve time is clearly insufficient to allow descent to a safe altitude or repair of a malfunction in the oxygen equipment. Therefore, the pilot must not take this time into his calculations, but must check the correct operation of the oxygen-respiration apparatus carefully for each flight.

Preventive Measures

The principal and most effective methods of preventing phenomena involved /86 in oxygen starvation and ensuring normal vital activity and working capacity of flight crews in high altitude flight are pressurized cabins, oxygen supplies, and high-altitude equipment.

In the pressurized cabins of modern fighter aircraft, during flight at high altitudes, a higher pressure is maintained than that in the surrounding atmosphere; this makes it possible to make effective use of the oxygen-respiration apparatus.

Since the lack of oxygen begins to be apparent at 2,000 m during a climb, it is necessary to use the oxygen apparatus to maintain the partial pressure of oxygen in the alveolar air within the limits of physiological norms beginning at this altitude. It must be kept in mind that, when the oxygen system is switched on following prolonged oxygen starvation, there may be a /87
brief deterioration of the pilot's sensation (paradoxic effect). If a flight during the daytime is to last several hours, the oxygen supply must be switched on at 2,000 m. During night flights, the apparatus is usually switched on on the ground, since the low level of illumination means that the functions of the eye will deteriorate considerably even at insignificant degrees of oxygen insufficiency.

In fighter aviation, in view of the high rate of climb of the aircraft, the oxygen supply must be switched on by the pilot on the ground before a high altitude flight, before he takes off. This means that the equipment must be carefully adjusted and checked beforehand.

If aircraft cabin pressurization fails at altitudes above 10,000 m, the ordinary oxygen device of the "pulmonary automatic" type is unable to prevent oxygen starvation, and at altitudes of 11,000 to 12,000 m the first signs of disruption of certain visual functions make their appearance. At altitudes above 12,000 m, the shortage of oxygen becomes very significant, and serious functional changes occur in the organism, creating a danger to life.

The reason for this situation is that at altitudes above 12,000 meters, using oxygen devices of the pulmonary-automatic type in a depressurized cabin, it is not possible to create the partial pressure of oxygen in the alveolar air required for normal vital activity due to the low total pressure, the increase in the specific value of the water vapor, pressure, and the partial pressure of carbon dioxide in the alveolar air. Thus, we know that in the alveolar air the partial pressure of water vapor is equal to 47 (and that of carbon dioxide, approximately 40) mm Hg. In addition, medical oxygen contains approximately 2% nitrogen, which corresponds to a pressure of 5 mm Hg. Hence, the total partial pressure of the water vapor, carbon dioxide, and nitrogen in the alveolar air $p = 40 + 47 + 5 = 92$ mm Hg.

When using ordinary oxygen equipment, oxygen is supplied to the lungs under pressure equal to atmospheric pressure. Consequently, the partial pressure of oxygen po_2 in the alveolar air will be equal to the difference between the total barometric pressure (B) at the given altitude and the sum of /88
the partial pressures (p) of the water vapor, carbon dioxide and nitrogen in this air: $po_2 = B - p$.

Then, for example, at an altitude of 13,000 m, where B = 124 mm Hg, $po_2 = 124 - 92 = 32$ mm Hg, while at an altitude of 14,000 m at B = 106 mm Hg, $po_2 = 106 - 92 = 14$ mm Hg.

In reality, however, when breathing pure oxygen, its partial pressure in the alveolar air will be somewhat higher than the calculated value (Table 8), since under these conditions there is an increase in pulmonary ventilation, and consequently, a drop in the carbon dioxide content in the alveolar air.

When using ordinary oxygen devices of the pulmonary automatic type in depressurized cabins at altitudes above 12,000 m, the pilot may retain his working ability only for a very limited time, which is insufficient for taking active measures to save himself (ejecting or descending to safe altitudes).

Differences in the survival rate of animals of a given type (for example, dogs) are very apparent at altitudes of 13,000-15,000 m, while at altitudes above 16,000 m their survival is practically the same. The principal reason for the rapid death of animals under these conditions is a rapid decrease in the oxygen pressure in the blood. The high rate of development of severe oxygen starvation is explained not only by the sharp drop in the partial /89

TABLE 8.

Altitude, m	Barometric pressure mm Hg	Partial pressure of O_2 in alveolar air, mm Hg	
		Calc.	With correction for increase in pulmonary ventilation
[illegible]	[illegible]	106	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]

pressure of oxygen in the surrounding atmosphere, but also by the phenomenon (characteristic for these altitudes) of loss of blood gases ("degassing of the organism"). At high degrees of rarefaction, the pressure of gases (oxygen, nitrogen and carbon dioxide) in the blood is higher than their pressure in the surrounding atmosphere, so that these gases begin to switch from the blood into the alveolar air. In modern aviation, in order to protect against oxygen starvation in the event of a breakdown in the pressurization of the aircraft cabin, flying suits are worn and oxygen devices are provided for breathing oxygen under excess pressure.

The pressurized suit provides reliable protection for the pilot not only against the effects of a sudden oxygen starvation, but also against low temperatures and large and severe pressure changes. However, the suit has a number of important disadvantages, which dictate against its use in aviation (limitation of mobility, large size, etc.).

These disadvantages are not shared by oxygen devices which supply oxygen to the lungs at high pressure. In a pressurized cabin, a device of this kind operates as a normal device for pulmonary automatic operation, but when the cabin is depressurized at altitudes above 12,000 m continuous supply of oxygen is automatically cut in and excess pressure is created beneath the mask.

These devices maintain the constant minimum necessary excess pressure of oxygen in the lungs regardless of atmospheric pressure in the aircraft cabin. The total oxygen pressure in the lungs is made up of two values: atmospheric pressure at the given altitude and some excess pressure of oxygen created by the device. Depending on the value of the total pressure, oxygen devices can be divided into those which work at a pressure level of 115 mm Hg (first mode, or "mode 115"), at a 130 mm Hg mode (second mode, or "mode 130") and in a mode of 145 mm Hg (third mode, or "mode 145").

Oxygen devices that work in the first mode are recommended for use at altitudes up to 15,000 m; those with the second mode — at altitudes up to 18,000 m; and those of the third mode — at altitudes above 18,000 m. In the first case, a special oxygen mask is used; in the second, an oxygen mask and /90
a special altitude compensating suit, which creates counterpressure on the surface of the trunk and the extremities; in the third case, a pressurized helmet and a compensating suit (oxygen supply system).

When working in these pressure modes, approximately the same conditions for respiration are created as when using oxygen devices of the "pulmonary automatic" type at altitudes of 12,000-13,000 m.

The oxygen equipment system, which consists of the oxygen device, pressurized helmet, and compensating suit during work at the third mode provides the possibility of staying and retaining high working ability at altitudes above 20,000 m in a nonpressurized cabin for a rather long time. However, the effectiveness of this system is less than that of a flight suit. This is explained by the fact that in the flight suit a "pneumatic" system is used to create a uniform counterpressure over the entire surface of the body, while in the altitude-compensating suit of the oxygen supply system a

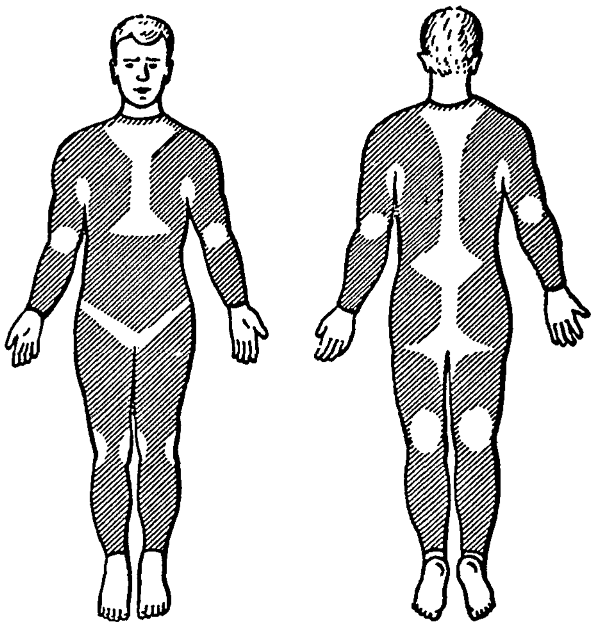

Figure 20. Portions of body with insufficient pressure from flying suit (unshaded).

"mechanical" system is employed which distributes the counterpressure non-uniformly. For example, in the armpits, inguinal regions, perineal area, interscapular region and other places (Figure 20) the counterpressure is somewhat less than on other parts of the body. Therefore, at altitudes above 19,000 m it is possible to have congestive phenomena at these places which lead to sensations of pain. Nonuniformity of counterpressure distribution is a consequence primarily of design shortcomings in the compensating suit.

Increasing altitude resistance of the pilot's organism. Altitude resistance of the organism of the pilot is of primary importance in the decompression of the aircraft cabin, damage or breakdown involving the oxygen breathing apparatus.

An important role in increasing the altitude resistance is played by the organized physical training of the pilot.

In performing physical exercises, the requirements of the tissues for oxygen are increased, and the work of the respiratory organs increases as well. As a result, there is a decrease in the respiratory volume and the lung surface, pulmonary ventilation, oxygen content in the alveoli and its partial pressure; there is an increase in the amount of active pulmonary capillaries and alveoli. All of this has a favorable effect on the pulmonary gas exchange /91 and the general state of the organism. In addition to the reinforcement of the functions of the respiratory system, there is a favorable restructuring of the circulatory organs as well: the frequency and force of cardiac contractions increases; there is a rise in the venous influx of blood to the heart, a reinforcement of the minute and systolic volume of blood, the rate of circulation, and consequently, the supply of oxygen to the tissues; there is an increase in the mass of circulating blood and hemoglobin, the carrier of oxygen. At the same time, more favorable conditions are created for the transition of the oxygen from the blood to the tissues, and the tissues themselves become able to use oxygen more economically, while the activity of enzymes that participate in biochemical processes of the organism increases and metabolism is improved. The tissues make better and more economical use of nutrient substances. /92

Hence, the entire complex of physiological changes that occur in the organism during systematic performance of physical exercises makes it possible to increase its working ability and to raise the functional reserves making the organism more resistant to the effects of various flight factors.

We know from practical experience that physically strong pilots can withstand the effects of altitude much better. This is indicated by military experience during World War II and the fact that professional athletes who have had nothing to do with aviation or mountain climbing show very good altitude resistance when they "ascend" in barochambers.

During the organization of physical training in the units, it is necessary to consider the specific features of the flight activity. Thus, fighter pilots must have a different kind of physical preparation with predominant development of rate of reactions and strength endurance, capacity for withstanding considerable stresses both mental and physical and circumspection under conditions of rapidly changing situations, while the flight crew of a bomber should perform physical exercises that are directed at a strengthening the organism and increasing the working capacity on long flights.

Physical training must be performed with a consideration of the intensity of flight stress. During severe work in flight, the efforts at physical preparation must be directed to relieving emotional stresses and cutting down on fatigue; under low flying stress, these exercises should be recommended for performance in an expanded and more intensive program.

In order to increase altitude resistance, it is desirable to select those kind of sports in which the tissues of the organism undergo a certain oxygen insufficiency causing an increase in the activity of the respiratory and circulatory organs (swimming, running, skiing, etc.).

During the period preceding flights, it is necessary to perform exercises which increase the resistance of the organism to the effects of acceleration /93 (exercises on bars, horizontal bars and other equipment) and also to do exercises in water to strengthen and train the cardiovascular and nervous systems.

Improvement of three-dimensional orientation, increasing the rapidity of responsive reactions and strengthening the neuro-emotional sphere are made possible by exercises in gymnastics, acrobatics, participation in active sports, performing exercises in wrestling, etc.

At the present time, an extensive study is going on of the prolonged effect of oxygen insufficiency in the inspired air on the organism under high mountain conditions. Data are available which would indicate that during a prolonged stay under these conditions the human organism acquires increased resistance to the effects of oxygen deficiency, ionizing radiation, radial accelerations and physical stresses. Therefore, in several countries (for example, in West Germany) flight crews are made to stay in high-altitude areas. This, in conjunction with hospital-spa treatment and physical preparation, has a positive effect on increasing the altitude resistance of the organism. It is highly possible that in the near future periodic stays of pilots in high mountain camps will occupy a prominent place in the list of measures taken to increase the resistance to the effects of unfavorable flight factors.

Among the measures which increase resistance of the pilot's organism to altitude are correct organization of labor, rest, and nutrition.

In organizing the work regime, it is necessary to proceed on the basis of the fact that the duration of flights (by the day or week) need not increase the maximum standards established for a given type of aviation. The flight stress for each pilot must be determined with a consideration of his state of health and working ability. It is not permissible to allow an unjustifiably long stay of pilots at the airport. Here conditions must be created which insure protection against the unfavorable influence of various factors of the external medium. To do this, it is necessary to take into account the climatic characteristics of a given region, the time of year and the nature of the weather.

In organizing the rest of the flight crew, it is necessary to have a /94 sensible mixture of rest, active participation (sports, walking, swimming, etc.) and entertainment which will create positive emotions. All of this makes it possible to prevent or rapidly relieve fatigue and restore working ability. Before a high-altitude flight, no excessive physical overstress should be allowed. During the days of training on the ground, strict observation of the established order of exercise and rest must be observed. The flight crew must have at least 8 hours of sleep each night. Lack of sleep and insomnia sharply reduce working ability.

In accordance with the general regulations, the flight crew has days off and an annual vacation of a certain length. In addition, depending on the doctor's findings, the flight crew is given a periodic brief rest at special dispensaries.

Changes in Barometric Pressure and Their Effect on the Human Organism

In aviation medicine, a change in barometric pressure is understood to be an increase or decrease in the pressure in the surrounding atmospheric medium. From the physical standpoint, however, a pressure change is considered to be the actual difference between the pressure in the pressurized cabin of the aircraft and the pressure outside it, i.e., atmospheric pressure at a given moment.

Increasing the atmospheric pressure is called a compression change, while a decrease is called decompression. The effect of decompression is felt by the pilot when he ascends to a high altitude, in the case of an accidental breakdown in the pressurization of the cabin and during barochamber tests, as well as during descent (diving) when he is exposed to the effects of compression change. When aircraft had nonpressurized cabins, comparatively low flight altitudes (7,000-8,000 m) and low rates of climb, the compression change exerted a significant influence on the pilot's organism, since in these planes it was possible to reach considerable vertical speeds (and, consequently, a significant and rapid change in barometric pressure) only when diving. Under modern conditions, however — when practically all aircraft are equipped with /95 pressurized cabins, have high vertical rates of climb, and fly at altitudes above 10,000 m — the influence on the pilot of decompression changes has increased immeasurably.

Changes in barometric pressure are characterized by magnitude, duration, speed, and frequency.

By the magnitude of the change, we mean the difference (in mm of Hg) in the barometric pressure in the aircraft cabin before and after its depressurization. For example, if at an altitude of 15,000 meters prior to cabin depressurization the barometric pressure were 391, and 91 mm Hg after decompression (barometric pressure at an altitude of 15,000 m), the magnitude of the decompression change at this altitude would be equal to 300 mm Hg.

The duration of the change is determined by the time required for complete equalization of pressure in the cabin with the pressure in the surrounding atmosphere at a given flight altitude. The duration is expressed in seconds or fractions of seconds. The rate of change is the change in aircraft cabin pressure in mm of mercury in one second. The rate depends on the magnitude and duration of the change. For example, if the magnitude of the change is 220 mm Hg and the duration is 10 seconds, the rate will be equal to 22 mm Hg per second. At a given magnitude of change, the greater the duration of the change, the less its rate. Consequently, the lower the value and the higher the duration of the change, the more easily it will be withstood by the pilot's organism.

The frequency of the change is expressed by the ratio of the pressure in the cabin before its decompression to the pressure in the surrounding atmosphere, i.e., to the pressure established in the cabin following decompression. For example, if decompression of the cabin took place at an altitude of 10,000 m at a cabin pressure of 419 mm Hg and the barometric pressure at this altitude were equal to 199 mm Hg, the frequency of the drop would amount to $419:199 \approx 2.1$.

Decompression may be slow or rapid. Slow decompression is observed in practice in every flight, since, depending on the pressure regime adopted for pressurized cabins, the pressure in them continuously decreases with a climb to a certain altitude. Rapid decompression may occur as the result of the accidental decompression of the aircraft cabin at high altitudes. This form of pressure change has come to be called explosive decompression. /96

The change (decrease or increase) in barometric pressure during high altitude flights may cause painful sensations in the region of the middle ear and the accessory sinuses of the nose. The more rapid and significant these changes, the more intensive the pain can be. Their development is promoted by sharp and chronic inflammatory processes of the nasopharynx. As a rule, these painful sensations occur during compression pressure changes, i.e., with a drop to an altitude of 3500 m or less.

A comparatively slow decompression, pain in the ears, and accessory sinuses is observed only in individuals with diseases of the nasopharynx or the middle ear.

Pain in the ears and accessory sinuses in most cases disappear immediately after the flight, but sometimes may persist for several hours and very rarely for several days.

Decompression DISORDERS

The most active effect of a change in barometric pressure on the organism has been studied in recent decades in conjunction with increased flight altitude of aircraft. A considerable contribution to the solution of this timely problem was made by Soviet scientists, A. P. Apollonov, V. V. Strel'tsov, D. I. Ivanov, D. Ye. Rozenblyum, M. P. Brestkin, V. A. Spasskiy, V. G. Mirolyubov, A. P. Popov, P. K. Isakov, A. G. Kuznetsov, O. G. Garzenko and A. M. Genin.

For a long time it was felt that a drop in barometric pressure had an unfavorable effect on the organism only because of oxygen starvation. Of course, the leading factor that causes such effects is oxygen starvation, but, as we have already pointed out, at altitudes above 8,000 m the negative effect of decompression acquires considerable importance. So-called decompression disorders may occur in the organism under these conditions. They are /97 accompanied by phenomena that are completely dissimilar to the phenomena linked to oxygen starvation. At the present time, it is customary to distinguish three basic forms of decompression disorders: altitude sickness, altitude meteorism, and altitude tissue emphysema.

There are two causes which form the basis of the development of decompression disorders:

1) A change of gases contained in liquid and semi-liquid media of the organism from the dissolved to the gaseous state;

2) Expansion of gases that are in a free state in empty organs and cavities (lungs, gastrointestinal tract, middle ear, accessory cavities of the nose, frontal sinus).

Depending on the magnitude, rate and duration of decompression, as well as the state of the organism, the degree of occurrence of decompression defects may differ from scarcely noticeable symptoms to irreversible damage. The frequency of occurrence of disorders also depends on these characteristics: with an increase in the magnitude, rate and duration of decompression and deterioration of the state of the organism, they will increase.

Altitude Sicknesses

The characteristic form of decompression disorders of this type are pains in the joints, muscles, and the tissue surrounding them. Usually they are observed in the large joints of the extremities — in the knees and elbows, and somewhat rarely at the points where muscles are attached to the bones (or ligaments) and rarely in the small joints of the extremities.

Usually muscle-joint pains develop suddenly when making some movement and then increase. In certain cases they may disappear after a certain time interval but then return, sometimes in a more severe form. These pains may be of different intensity, from scarcely noticeable unpleasant sensations in a particular joint or muscle to excrutiating attacks which force the pilot to descend or even abandon the flight.

When the pilot in flight is in a resting state, i.e., is not making movements, muscle-joint pains usually show up to a lesser degree, but during /98 any kind of movement or physical work they appear more frequently and in a more severe form.

They usually develop at an altitude of 8,000 m or more and in the majority of cases during the first 30 minutes of staying at a specific altitude, but they may also occur after several hours of high-altitude flight.

When descending to 6,000-7,000 m or less, the muscle-joint pains disappear, but frequently there is some residual sensation of discomfort in the affected joint or muscle, and there is a feeling of general weakness and exhaustion. All of these phenomena disappear completely after several hours following the flight, or in serious cases after a night's rest.

If the pains disappear following descent to an altitude below 8,000 m, they may return when the pilot climbs again to his original altitude. Cases are known when the moderate muscle-joint pains disappeared after a short time at the same altitude at which they developed.

Other forms of altitude sickness are: itching of the skin, altitude coughing, retrosternal pain, pains along the roots of the nerve trunks, and disturbances related to the stimulation of the higher sections of the central nervous system.

Itching of the skin resembles the itching that develops following the biting of insects. It is comparatively frequently combined with muscle-joint pains, but may develop independently. In terms of intensity, it may be mild to intolerable, completely disrupting the working ability of the individual. Most frequently, the itching is localized on the skin of the back, chest and stomach. In the affected areas, redness and edema appear, reminiscent of urticaria. In some people, the itching of the skin develops every time they go above 8,000 m.

Altitude coughing begins with an unpleasant sensation and tickling in the throat. Then definite coughing movements develop, which change to severe attacks of coughing. This disrupts respiration and circulation, so that it is frequently observed to turn into a more severe condition. At the first signs of such a disturbance, the pilot must immediately descend to an altitude /99 of 6,000-7,000 m in order to avoid the unpleasant consequences.

Retrosternal pains may develop simultaneously with altitude coughing or completely separately. This form of pain is reminiscent of the pain that is characteristic of stenocardia. In rare cases, it may also be accompanied by actual stenocardia, especially against a background of oxygen insufficiency. In contrast to true stenocardia, retrosternal pains disappear comparatively rapidly following descent to an altitude of 6,000-7,000 m.

Sometimes pains develop along the pathways of the nerve trunks, and this may be in conjunction with paresis, loss of skin sensitivity, and even paralysis of the extremities.

An extremely rare but very dangerous form of altitude sickness is the disorders that occur as the result of damage to the higher sections of the central nervous system. The picture of the development of such disturbances is complex and diverse. Usually the first stage is marked by pronounced signs of cardiovascular insufficiency, disruption of respiration, pulmonary edema, dizziness, paleness, excessive perspiration, fatigue, blurring of vision, and total loss of consciousness. Sometimes loss of consciousness may occur suddenly. In the foreign literature, there are descriptions of actual fatal outcomes in this kind of decompression. According to American data, one such case occurred in 100-200 thousand climbs to an altitude of 8,000 m or more. After making their appearance under conditions of decompression, the defects which involve irritation of the central nervous system are largely reduced or completely disappear upon descending to an altitude of 6,000-7,000 m. A state of apparent well-being ensues. However, after a short time, sometimes 10 to 14 hours later, the state of the individual deteriorates sharply. There are progressively increasing symptoms of damage concentrated in the central nervous system, combined with symptoms of cardiovascular insufficiency, destruction of respiration, and pulmonary edema.

In view of the characteristics of occurrence and the danger of the processes involved in these defects, it is recommended that their unfavorable consequences be prevented during the first hours following a climb by providing the pilot with rest and limiting his physical stress. /100

Special attention must be given to people in whom symptoms of not feeling well, dizziness, headache, weakness, and especially blurring of vision or loss of consciousness appear under conditions of decompression. Following descent, they should have complete rest for several hours. In case of deterioration of their condition, they must be immediately brought to a clinic in an ambulance, with appropriate precautions being taken. Proper first aid and medical assistance rendered by qualified personnel can produce a favorable outcome even in very serious cases.

The frequency of occurrence of decompression disorders (altitude sicknesses) is increased with the increase in magnitude, duration, and rate of decompression, and also the physical stress. This is indicated by data which are listed in Tables 9-11. In this regard, there are no definite and strictly regular relationships.

According to the data of certain American investigators, the frequency of /101
development of decompression disorders at altitudes of 8,500-9,000 m for more than 15 min may reach 40%, and at altitudes of 11,500-12,000 m — 95% of the total number of ascents.

It has been established that under identical conditions, decompression pains may occur in some people and be completely absent in others. Even in the same individual under the same conditions, on some days there may be difficulties and none on others. It is also true that for some people they develop every time at the same altitude and in a certain sequence.

Many investigators feel that the development of these decompression defects is furthered by extreme fatigue of the organism caused by over-tiredness, a state of illness, insufficient sleep, use of alcohol or excessive smoking, as well as general and local overcooling, sitting in a single position, tight and uncomfortable clothing.

It is also known that individuals with metabolism disorders (excess weight) and persons of advanced age more often show signs of decompression defects.

TABLE 9.
(Hitchcock, 1959)

Altitude, m	Number of ascents	No. of cases with signs of pain, %
10,000	92	7.6
11,000	111	55

TABLE 10.
(D. Ye. Rozenblyum, 1953)

Altitude, m	Time spent at altitude, min	No. of cases with signs of pain, %
8,000	120	5
10,000	10	2.3
	10-20	9.6
	20-30	16.7
	30-40	18.1
	more than 40	53.3

TABLE 11.

Conditions of ascent to altitude of 11,600 m	Frequency of disorders (%) with rate of drop, mm Hg cm/sec.		
	35	104	208
Without physical stress	7.6	24.2	33.3
With stress	55	62.2	67.6

This evidently has to do with a deterioration of blood circulation and a slower liberation of nitrogen through the lungs.

Frequently, decompression pains develop in the sites of old wounds and bone breaks.

The fact that when the barometric pressure falls (decompression) an individual can develop certain disorders has been known for more than 100 years. It was first discovered in connection with the work of caisson workers and /102 divers. However, the reason for these disturbances remained unknown for a long period of time and various hypotheses and theories were expressed.

At the present time, the caisson (nitrogen or gas) theory of development of high-altitude sickness is the one that is most generally accepted. According to this theory, the pain is caused by the passage of nitrogen into the tissues and into the blood from the dissolved to the gaseous state due to a significant drop in barometric pressure. The pains that then develop are the result of mechanical action (pressure) on the nerve endings of gas bubbles that are formed in the tissues or the result of plugging of small blood vessels by gas bubbles that form in the blood.

According to the law of diffusion of gases between tissues, liquid, and semi-liquid media of an organism, on the one hand, and the external medium (atmosphere) on the other, there is a certain gaseous equilibrium. The component parts of the air are dissolved in the blood in certain amounts. It has been established experimentally that at normal atmospheric pressure (760 m Hg) 100 cc of blood can contain about 1.5 cc of nitrogen, 0.36 cc of oxygen and 2.7 cc of carbon dioxide in solution. The nitrogen dissolves fastest and to the greatest extent in the fats of the organism. At normal body temperature and barometric pressure, nitrogen is dissolved in them about six times more than in the blood. At a given pressure, the tissues of the organism are completely saturated with atmospheric nitrogen. This means that the body of a man of average weight contains about 1.5 liters of nitrogen in solution.

Liquid and semi-liquid media of the organism may be oversaturated with gases. In this case, the process of solution of gases is interrupted. This state of the medium is characterized by the saturation coefficient. For nitrogen, this coefficient is equal to approximately 2.25, but the gas is still in a dissolved state and no gas bubbles are formed. At barometric pressure

corresponding to an altitude of more than 8,000 m, the supersaturation coefficient with nitrogen reaches a value of about 2.5. Under these conditions, the nitrogen pressure in the tissues and the blood becomes higher than its partial pressure in the alveolar air of the lungs. As a result, according to Dalton's law, the nitrogen in the tissues and the blood passes from the /103
dissolved state into the gaseous state, forming gas bubbles.

As we have already mentioned, decompression pains disappear after a short time has elapsed after an altitude of 8,000 m or more is reached (in a decompressed cabin). This is explained by the fact that a certain period of time is required to form the bubbles of nitrogen and make them grow; this time decreases as the degree of supersaturation of the tissues with nitrogen increases and the duration of decompression decreases. Bubbles form to the greatest degree in the tissue of organisms that are rich in fat.

Since the removal of nitrogen from the tissues takes place essentially through the blood vessels, tissues with an insufficiently developed vascular network have a much more difficult time and are slower in getting rid of the excess nitrogen. Development of pain, primarily in the joints, is explained precisely by the fact that the bursae of the joints are poorly endowed with blood vessels.

The gas theory of decompression pain is supported by x-ray studies. During muscle-joint pains, x-ray pictures frequently show gas bubbles in the affected joint or the tissue surrounding it (Figures 21 and 22). The concepts of this theory are supported by experiments with preliminary "washing out" of nitrogen from the organism (desaturation) by breathing pure oxygen.

The essence of desaturation is the fact that, when pure oxygen is breathed, the partial pressure of the nitrogen in the alveolar air decreases rapidly and a difference between the partial pressure of nitrogen of the alveolar air of the lungs and its pressure in the venous blood develops.

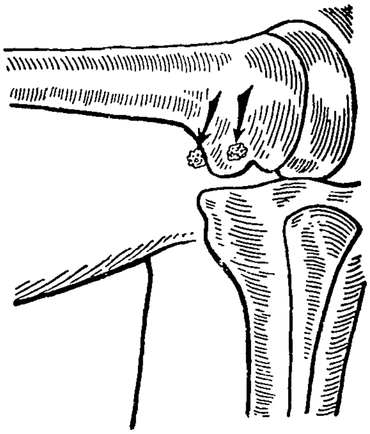

Figure 21. Gas bubbles in the area of the human knee joint (altitude 12,000 m, desaturation with respect to nitrogen not performed).

Figure 22. Gas bubbles in the cerebral convolutions of a dog.

Consequently, the nitrogen passes from the blood into the alveolar air and is expelled into the atmosphere with every breath. Returning from the lungs to the tissues, the blood again is saturated with nitrogen, again goes to the lungs where the process of desaturation continues. With each circulation of the blood, the pressure of nitrogen in the tissues and blood decreases. After breathing pure oxygen for an hour immediately before ascent, as a rule, the possibility of development of decompression disorders for the next two to three hours at altitudes up to 12,000 m is prevented. Therefore, all of the laboratory tests that involve "ascents" of individuals in a barochamber to altitudes above 7,000 m are conducted with a necessary preliminary desaturation of the organism for a period of time no less than 1 hour.

Studies conducted in recent years have shown that gas bubbles in the tissues during decompression may be formed as a result of the transition to a gaseous state not only of nitrogen but also carbon dioxide and oxygen. This /105 is explained by the fact that decompression pains occur most frequently in the case of active muscular work, which, as we know, is accompanied by an increase in the formation of carbon dioxide in the tissues. There is a basis for believing that, at the very beginning of development of decompression disorders, due to the transition of carbon dioxide to the gaseous state, the first gas nuclei are formed, which then grow as a result of subsequent diffusion of nitrogen into them and become bubbles.

According to the other theory which is called the "fat" theory, one of the possible causes for development of decompression pains is a fatty embolism — blockage of blood vessels by small droplets of fat.

As we know, the principal mass of the nitrogen dissolved in the organism is contained in the fatty tissue. Therefore, under conditions of decompression, the gas bubbles may initially be formed in the fatty cells and break them up. Droplets of fat and lipids from the broken fatty cells may travel along the lymph pathways into the general circulation of the blood and finally block the small blood vessels. As a result, painful sensations occur.

In tests of animals that were specially exposed to the action of explosive decompression, investigators have frequently seen blockage of blood vessels by droplets of fat (embolism).

It should be pointed out that the "fat theory" does not exclude the gas theory; both theories are equiprobable to a certain extent.

Preventive Measures. One of the most important ways of preventing decompressions disorders at high altitudes is pressurization of aircraft cabins. The pressure in the pressurized cabin must not fall below 267 mm Hg, which corresponds to an altitude of 8,000 meters. The pressure in the pressurized cabins of modern military aircraft is regulated automatically depending on the flight altitude, and must exceed the pressure of the surrounding atmosphere by /106
220-300 mm Hg (by 0.3-0.4 atm).

A second effective method of preventing decompression disorders is the desaturation of the organism with respect to nitrogen by breathing pure oxygen prior to ascent. For this purpose, aviation oxygen systems may be employed. When breathing pure oxygen, a third of the nitrogen dissolved in the tissues is removed from the organism during the first 10 to 15 minutes, with the most of it being disposed of during the first 3-4 minutes. The remaining 2/3 of the nitrogen is excreted rather slowly. For complete desaturation of the organism with respect to nitrogen, it is necessary to breathe pure oxygen for at least 5 hours. We should note that absolute removal of nitrogen from the organism can never be achieved, since medical oxygen used for respiration contains about 2% nitrogen.

Prolonged desaturation of the organism with respect to nitrogen is accompanied by a number of disadvantages. On the basis of the barochamber experiments under conditions of high rarefaction of the atmosphere, it has been found to be completely possible to reduce the desaturation time to 1 hour. Although nitrogen still remains in the organism under these conditions, decompression pains develop much more rarely and disappear after taking a much milder form.

Unfortunately, this method of prevention is not used in aviation at the present time, since the pilot must remain for a long time in the aircraft cabin. It is true that if we proceed on the basis of the fact that, under existing pressure modes in pressurized cabins and normal conditions of flight, the development of decompression problems is excluded, there is no real need for preliminary desaturation of the organism with respect to nitrogen.

A certain amount of preventive significance has been acquired by the mode of using oxygen devices, switching them on at the moment the flight begins. During the flight, there is a partial desaturation of the organism with respect to nitrogen, and in the case of decompression of the cabin at great altitudes the danger of serious decompression disorders is reduced to a considerable extent, but not completely excluded, especially if decompression occurs soon after takeoff (incomplete desaturation).

TABLE 12.

Altitude, m	Barometric pressure, at m	Increase factor of gas volume
0	1	1
5 500	1/2	2
8 400	1/3	3
10 300	1/4	4
11 600	1/5	5
12 400	1/6	6
14 000	1/7	7
16 000	1/10	10
20 000	1/20	20

Altitude Meteorism

Altitude meteorism (distention of the stomach) is caused by an increase of the volume of the gases in the gastrointestinal tract and the air which is swallowed with food. Under ordinary conditions, the gases which are always found to some extent in the stomach and especially in the large intestine are under a pressure equal to atmospheric pressure. When the barometric pressure decreases following a climb to a certain altitude, these gases and the air expand and increase in volume. With free expansion, the volume of any gas increases to the same extent that the atmospheric pressure decreases. This is clear from Table 12, where for the sake of an example we have listed the data regarding the relative change in the unit volume of a gas (dry air) with altitude. /107

During an ascent, the gases in the gastrointestinal tract increase in volume to a lesser degree than dry air under conditions of free expansion, since in the first place a higher pressure is maintained in the cabin than in the surrounding atmosphere, and in the second place there is elastic resistance of the walls of the gastrointestinal tract and the muscles of the abdominal prelum.

Due to expansion of the gases and the air in the gastrointestinal tract, the diaphragm is displaced upward. This causes a reduction of the depth of respiration, vital capacity of the lungs, and pulmonary ventilation. In addition, the flow of the blood to the heart is made more difficult and circulation is disrupted.

As a result of the expansion of the gases, the walls of the stomach and intestine stretch, and the sensitive nerve endings in them are mechanically /108 stimulated (by the pressure), causing painful sensations in the stomach. The frequency of occurrence of feelings of bulging, heaviness, and pain in the stomach and their intensity increase with increasing magnitude and rate of decompression, and also when using foods that cause considerable gas formation. Sharp pains in the stomach may be the cause for deterioration of the total condition (weakness, cold sweat, severe slowing down or speeding up of the pulse and respiration, belching, fatigue, nausea, slight blurring of vision may develop) and reflexes are triggered that inhibit the heart activity. Against this background, one may frequently see inhibition of the activity of the central nervous system and a drop in working ability.

Altitude meteorism may occur when the feeding regime is disrupted, during emergency depressurization of the cabin, or during high altitude test "ascents" in the barochamber. A rapid drop to a safe altitude gets rid of problems of this sort and normal sensations return.

In many cases, with comparatively slow decompression, the bulging of the stomach for a short time is reduced by release of gases from the intestines and from the stomach as a result of belching. The pain of the stomach is relieved following this action.

To prevent altitude meteorism, the following are recommended:

a) The ration to be eaten before flight should exclude products which produce large volumes of gas (peas, beans, etc.);

b) Immediately before flight, the intestines should be emptied (especially by persons who are subject to accumulation of gas in the stomach) as well as the urinary bladder;

c) The functions of the gastrointestinal tract should be kept in a normal state.

Altitude Tissue Emphysema

Altitude tissue emphysema (subcutaneous swelling), unlike altitude pain, develops with a much greater rarefaction of atmosphere at high altitudes.

The development of altitude tissue emphysema is linked to the formation of water bubbles in the tissues due to a sharp drop in pressure and boiling point (bubble formation) of water. /109

It is clear from physics that the boiling point of water decreases with altitude, i.e., with a decrease in barometric pressure (Table 13). This law is obeyed by both liquid and semi-liquid physiological media in the body. If we assume that the boiling point of these media is close to the temperature at which water boils, we can expect that at their usual temperature (about +37°C) boiling (bubble formation) will take place at atmospheric pressure equal to 47 mm Hg (this pressure corresponds to an altitude of about 19,200 m).

TABLE 13.

Altitude, m	Barometric pressure, mm Hg	Boiling point of water, °C
0	760	100.0
2 000	596	92.5
4 000	462	85.5
6 000	354	79.0
8 000	268	72.5
10 000	198	65.5
12 000	145	58.5
14 000	106	51.5
16 000	77	46.0
18 000	56	39.5
20 000	41	35.0
25 000	19	22.0
30 000	9	10.0

Experiments conducted in a barochamber on animals confirm this view. Thus, for example, it has been found that at a given pressure (47 mm Hg), even with sufficient supplies of oxygen, subcutaneous swelling develops in animals after several seconds (rarely as long as 3-5 minutes) and rapidly develops in the areas of the neck, back, and stomach.

The development of altitude tissue emphysema is as follows. As a result of the boiling of the biological liquid in the loosest tissues (panniculus adiposus, fatty tissue), bubbles of water vapor are formed. Due to diffusion of nitrogen and carbon dioxide dissolved in the tissues, the bubbles begin to /110 expand gradually. After they reach a certain size and pressure of the water vapor and gases, these bubbles overcome the elastic and plastic forces of the tissue and disturb their structure. It is at this time that the rapid growth of emphysematous bubbles (swellings) begins.

The process of boiling (bubble formation) may be observed in other soft tissues, as well as in cavities which have a serous liquid in them (the stomach, pleural cavity, joints).

There is a theory, based on a number of studies, that the initial bubbles contain nitrogen and carbon dioxide. But the principal component is still water vapor. This is indicated by the fact that the bubbles gradually disappear when the pilot descends to an altitude of 18,000 meters or less.

Under similar conditions, and in man, subcutaneous swellings also appear on the exposed parts of the body (Figure 23). Under these conditions, it usually places a stress on the skin and very rarely causes slight pain. If the phenomenon spreads to the joints, their mobility may be limited and the performance of working operations will be inhibited. Emphysema rapidly disappears when the pilot descends to altitudes below 18,000 m.

Altitude tissue emphysema, as a local process that is limited to a certain part of the exposed surface of the body, poses no direct danger to life.

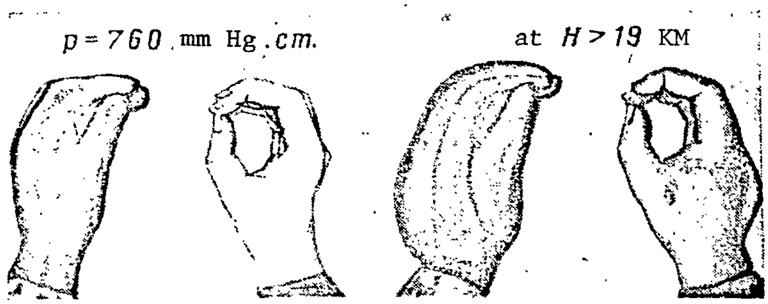

Figure 23. Altitude tissue emphysema of a cyst.

To prevent altitude tissue emphysema, special devices are used which create additional (compensating) pressure (50-60 mm of water column) on the exposed surface of the human body. These include compensating gloves and socks. /111

Explosive Decompression

Explosive decompression is a sudden, sharp drop in barometric pressure as the result of accidental breakdown in the pressurization of an aircraft cabin.

Explosive decompression is a particular case of decompression in general. Therefore, everything that has been said about the influence of decompression on the organism is completely valid when referring to explosive decompression. We should only mention the specific aspects of its effect. In explosive decompression, a very important influence is exerted not only by the sharp drop in barometric pressure itself in the cabin, but also by the high nervous and emotional stress caused by the emergency situation.

Therefore, explosive decompression — being a powerful and unusual stimulus — acts on the entire organism and causes complex response reactions in the higher sections of the central nervous system. Under these conditions, the pilot may develop a feeling of confusion and fear, which will disturb his activity for a certain period of time, so that he may make erroneous movements and complicate the situation.

The principal danger of explosive decompression is the fact that, as a result of sudden and sharp expansion of air in the lungs, the cavity of the middle ear, the accessory passageways of the nose and the frontal sinus and the gases in the gastrointestinal tract, there may be damage to these hollow organs, especially the lungs. The nature of the damage to the lung tissue may differ: in some cases, there are superficial bruises on the lungs against the internal space of the chest cavity, the heart and the large vessels or through the diaphragm against the liver, while in others there may be tears in the lung tissue. At critical levels of decompressive pressure decrease, there may be bruises and tears of lung tissue at the same time.

At the moment of explosive decompression, the individual seems to feel a blow on the chest, a rapid involuntary exhalation is caused, and the pressure in the lungs reaches that of the environmental in the course of 1-2 seconds. After expiration, there is a brief (10-15 seconds) delay in respiration, followed by several arrhythmic respiratory cycles, and respiration rapidly is restored. Maintenance of respiration is a reflex protective reaction of the organism which develops with the active participation of the central nervous system. It is aimed at limiting the expansion of the lungs and preventing tearing of the lung tissue. Such a reaction is the result of a simultaneous stimulation of a large number of sensitive nerve endings that are located in the lung tissue, gastrointestinal tract, and muscles which participate in the act of respiration, and an increase in the flow of nervous impulses from these endings (both in terms of quantity and intensity) to the higher sections of the central nervous system.

The nature of the functional disorders, as far as the organs of respiration and mechanical damage of the lung tissue is concerned, depends primarily on the length and magnitude of the pressure decrease: the sharper and greater the pressure drop (especially at a high original pressure level), the more important these disruptions and the greater the danger of damage to the lungs.

The phase of respiration at which decompression takes place is not insignificant (during the inspiration phase, the danger of harm to the lungs increases; the lung tissue is at its maximum distension), nor is the state of the trachea, bronchi, and the lung tissue itself. When there is an inflammatory process in the lungs and respiratory pathways, mucous accumulates, so that the resistance to expiration increases and this raises the danger of harm to the lungs.

Damage to the lungs can occur if the intrapleural pressure exceeds the limit of mechanical strength of the lung tissue. It has been established experimentally that in animals these injuries (individual and numerous hemorrhages in the interior of the lungs and on their surfaces, tears in the lung tissue) develop in those cases when the intrapleural pressure exceeds the pressure of the surrounding atmosphere by 60-80 mm Hg (in the absence of counterpressure applied to the surface of the chest cavity).

It should be kept in mind that in man, the pulmonary tissue is much stronger than in animals. In man, even in daily life, conditions are frequently encountered in which excessive intrapleural pressure develops up to 100 mm Hg and more (for example, when coughing, sneezing, under considerable /113 physical stress, etc.). However, usually no damage is done to the lung tissue under these conditions.

Special studies and practice have shown that pressure changes at altitudes of 20,000 m and more lasting up to 0.5 seconds at existing pressure modes in pressurized cabins of aircraft and the use of modern systems of oxygen supply pose no danger to man. In very severe cases, only extremely small areas of darkening of the lung tissue have been observed which disappeared without a trace in the course of several days and had no lasting effect on the individual's health.

As a result of experiments on animals, it was found that, if the volume of the lungs during explosive decompression (relative to the initial value) increases by less than a factor of 2.4, no damage will ensure. When their volume increases by 2.4-3.1 times, individual hemorrhages and foci of local emphysema (expansion of lung tissue) may be found. The most extensive areas of hemorrhaging and breaks in the lung tissue can be formed when the volume of the lungs increases by more than 3.1 times.

With any increase in the volume of the lungs during decompression, the chest cavity expands. The degree of its expansion depends on the excess pressure in the lungs and the counterpressure which is created by the pressurized suit on the surface of the body.

Explosive decompression also affects the gastrointestinal tract. As a result of sharp expansion of the gases in this tract, there is a distention of the stomach (pronounced deformation of the abdominal cavity) and a rise in the intraabdominal pressure. Due to the excessive expansion of certain parts of the intestine, there may often be pronounced prolonged reflex spasms of other parts, which prevents the escape of gases, and sharp pains may, therefore, persist for a long time.

Explosive decompression also has an effect on the activity of the cardiovascular system. In the majority of cases there is a quickening of the pulse in the initial period, and a slight increase in the arterial pressure.

These changes occur due to neuro-emotional influences in response to the /114 emergency situation which arises and as the responsive reaction to rapid and significant distention of the lungs and the walls of the gastrointestinal tract.

Large and rapid changes in barometric pressure create within seconds and fractions of a second, favorable conditions for the development of decompression disorders. If, after explosive decompression, flight is continued at the same altitude, the probability of decompression disorders will increase.

The existing types of oxygen equipment will not exclude the possibility of decompression problems at altitudes above 8000 m.

Protection of the organism against the unfavorable influence of explosive decompression has in practice been achieved at the same time that the organism is protected against severe oxygen starvation, for which special altitude equipment is used (oxygen supply systems).

CHAPTER V

PRINCIPAL PHYSIOLOGICAL-HYGIENIC REQUIREMENTS FOR AIRCRAFT CABINS

The cabin of an aircraft is the work area for the crew. It contains the instruments and equipment which are required for controlling the aircraft. Conditions must be created in the cabin for normal vital activity of human beings. /115

The first aircraft, which had a very crude design, with low speed and flight altitude, had practically no cabins. An individual operating such an aircraft sat in an open cockpit. We know that, even at a flight speed of 40 km/hr, the pressure of the air is very apparent, makes breathing somewhat difficult, and considerably increases heat loss, while at speeds above 250 km/hr the counter pressure against expiration and pressure on the chest cavity, face and stomach, is so strong that it becomes impossible for the pilot to breathe. Therefore, as speed and flight altitude increased, the need developed to protect the pilot against the influence of the airflow and other unfavorable flight factors. With this purpose in mind, aircraft began to be supplied with suitably equipped cabins. Initially, these were cabins of the open type.

Further increases in altitude, speed, and flight duration forced aviation designers first of all to shift to the construction of closed cabins and then pressurized cabins, which provide better protection for the crew members against the influence of unfavorable factors of the external medium and increase their working ability to a significant degree.

Principal Types of Pressurized Cabins

Pressurized cabins are found in modern aircraft which fly at high altitudes and in the stratosphere. Cabins of this type are the most reliable method of protecting individuals against the unfavorable influences of high altitude and other flight factors. /116

Pressurized cabins differ from ordinary cabins in the fact that a higher barometric pressure is maintained in them than in the surrounding atmosphere. Due to the excess pressure and the use of oxygen-breathing apparatus, the required partial pressure of oxygen is also maintained. The possible development of decompression disorders is practically excluded in a pressurized cabin under normal conditions.

From the standpoint of physiology, it would be most advantageous to maintain normal atmospheric pressure (760 mm Hg) in the cabin at all altitudes. However, this would necessitate increasing the strength of the cabin walls due to the high excess pressure. This would result in a significant increase in the aircraft weight, and therefore would lower its flight qualities. In addition, in the event of accidental depressurization of the cabin at high altitudes, a real danger of serious decompression disorders would arise for the crew members due to the effect of the considerable pressure drop. Therefore, beginning at a certain altitude (usually 2,000 m) the total barometric pressure in the cabin is kept lower than normal atmospheric pressure, and its level decreases with altitude to a certain value.

The principal requirements currently imposed on pressurized aircraft cabins of different types may be formulated in general as follows:

— The microclimate of the cabin (total pressure, oxygen partial pressure and air temperature) must be as favorable as possible for human activity in flights at all altitudes accessible to aviation;

— The cabin must be sufficiently strong and exhibit the required pressurizability, have good heat and sound insulation, reliable electrical /117 power supply system and regulation, and the glass in the cabin must be such that the crew will have good visibility;

— The units and systems for aircraft control must be sensibly located and readily accessible; the instruments, controls, signals and indicators must correspond to the psychophysiological capacities of man.

The cabins of military aircraft must also have oxygen equipment for the crew members and rescue facilities for use in emergency situations.

Depending on the method of providing normal physiological-hygienic conditions for the activity of the crew, pressurized cabins can be divided into ventilated, regeneration, and oxygen-ventilated types.

Pressurized cabins of the ventilated type (Figure 24). To create pressure in a cabin of this type and to ventilate it, atmospheric air is used, supplied by a compressor. After passing through the blower, it goes through an air-conditioning system and enters the cabin. In the course of an hour, one man will receive 50 - 75 m^3 of air. The air leaves the cabin and is exhausted into the atmosphere through an automatic or manual pressure regulator. The air entering the cabin at all altitudes contains approximately 21% oxygen. In normal high-altitude flight, the given pressure conditions and air temperature /118 in the cabin are maintained by appropriate automatic regulators.

The level of excess pressure for a cabin of this type is determined primarily by the flying time at high altitudes. We know that the longer a man is at a given altitude, the more pronounced is the effect of the rarefied atmosphere upon him, and consequently his working ability is more seriously reduced. Therefore, in the pressurized cabins of aircraft designed for long (more than four hours) high-altitude flights, it is necessary to maintain a higher excess pressure than in the cabins of aircraft with a shorter (up to four hours) flying time at high altitudes.

In the cabins of aircraft with high-altitude flights not in excess of four hours (for example, fighter aircraft) the air pressure is equal to the outside atmospheric pressure (up to altitudes of 2,000 m, i.e., there is no excess pressure. Beginning at an altitude of 2,000 m, the excess pressure in the cabin is steadily increased, so that at an altitude of 10,500 m it reaches 220 ± 15 mm Hg (0.3 atm). This excess pressure is maintained up to the service ceiling of the aircraft. The total barometric pressure in the cabin at this ceiling must be at least 267 mm Hg, which corresponds to an altitude of approximately 8,000 m (Table 16).

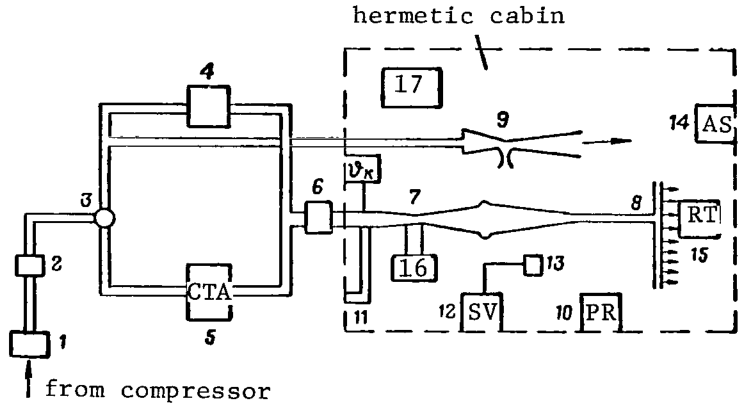

Figure 24. Diagram of a pressurized cabin of the ventilation type:

1 - shutoff valve; 2 - one-way valve; 3 - air distributor; 4 - flow regulator; 5 - cooling turbine assembly (CTA); 6 - one-way valve; 7 - Venturi tube; 8 - collector; 9 - ejector; 10 - pressure regulator (PR); 11 - fresh air intake; 12 - safety valve (SV); 13 - solenoid valve; 14 - altitude signal (AS); 15 - temperature regulator (RT); 16 - controlled mercury-arc rectifier motor; 17 - altitude and pressure difference indicator.

In the pressurized cabins of aircraft flying at high altitudes more than four hours (for example, bombers), the air pressure is kept equal to the outside atmospheric pressure up to an altitude of 2,000 m (in no case should it exceed that pressure by more than 30 mm Hg). At altitudes from 2,000 to 7,000 m, the cabin pressure remains constant, equal to atmospheric pressure at an altitude fo 2,000 m, i.e., 596 mm Hg. Then the assigned regime of excess pressure is gradually established. At altitudes of 8,000 m and more, a constant excess pressure equal to 294 $\pm$ 15 mm Hg (0.4 atm) is maintained. At the service ceiling, the total barometric pressure in the cabin must be at least 308 mm Hg, which corresponds to an altitude of 7,000 m (Table 14).

TABLE 14

Flight altitude, m	Barometric pressure, mm Hg	In the cabin of a fighter aircraft		In the cabin of a bomber aircraft	
		"Altitude", m	Pressure, mm Hg	"Altitude", m	Pressure, mm Hg
0	760	0	760	0	760
1 000	674	1000	674	1000	674
2 000	596	2000	596	2000	596
3 000	526	2450	565	2000	596
4 000	462	2850	535	2000	596
5 000	405	3300	508	2000	596
6 000	354	3700	480	2000	596
7 000	308	4050	460	2000	596
8 000	267	4350	440	2500	561
9 000	230	4650	425	3000	524
10 000	198	4900	410	3500	492
11 000	169	5300	389	4000	463
12 000	145	5750	365	4400	439
13 000	124	6200	344	4750	418
14 000	106	6600	326	5100	400
15 000	90	6950	310	5400	384
16 000	77	7250	297	5650	371
17 000	66	7500	286	5900	360
18 000	56	7750	276	6100	350
19 000	48	7950	268	6250	342
20 000	41	8150	261	6400	335

The excess pressure regimes at 0.3 and 0.4 atm are called basic. /119

In addition to the basic pressure regime, a combat regime is provided for the cabins of military aircraft: beginning at approximately 4,000-4,500 m altitude and up to the aircraft service ceiling, a constant excess pressure of 0.2 atm is maintained. This pressure regime is used in the zone of fighter activity to reduce the negative effect of decompression on the crew members, which is possible if the pressurized cabin is ruptured in combat.

On some aircraft, if the automatic pressure regulation mechanism should fail, excess pressure may be provided manually, changing it from 0.1 to 0.4 atm.

At the existing pressure regimes in pressurized cabins, the partial pressure of oxygen in the inspired air over the entire range of altitudes remains below the admissible level. Therefore, oxygen equipment is included /120
in cabins of ventilated type. The method of using this equipment is described in the corresponding instructions.

Pressurized cabins of the ventilated type are widely used for military and civilian aircraft. They are comparatively simple in design, convenient to use, and relatively inexpensive.

Pressurized cabins of the regeneration type (Figure 25). Cabins of this type have a closed air-changing system. They are completely isolated from the atmosphere, and the pressure and composition of the air in them are independent of the pressure and composition of the outside air.

It is assumed that regeneration cabins may be found in aircraft which do not have compressors for blowing as well as aircraft with high flight ceiling. It is technically unsuitable and disadvantageous to use compressors on the latter for producing excess pressure in the cabin, due to the excessively high degree of rarefaction of the air. Cabins of this type are found in spacecraft. The pressure in these cabins may range from normal atmospheric pressure to reduced pressure corresponding to an altitude of 10,000 m.

A special regeneration device is included in the cabin. The air, which is contained in the cabin, passes continually through this device with the aid of an electric fan (injector), and harmful impurities are removed (products of the vital activity of the organism). /121

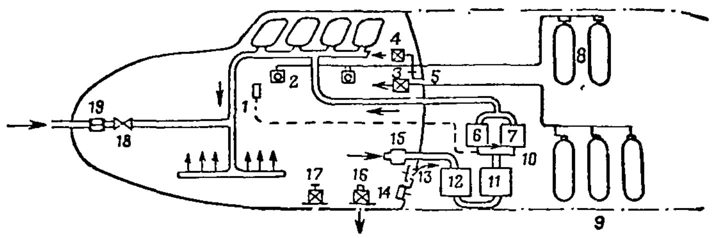

Figure 25. Diagram of a pressurized cabin of the regeneration type:

1 - temperature regulating sensor; 2 - oxygen-breathing apparatus; 3 - air intake regulator; 4 - oxygen supply regulator; 5 - emergency valve; 6 - cooler; 7 - heater; 8 - oxygen tanks; 9 - air tanks; 10 - slave-mechanism for heat regulator; 11 - moisture absorber; 12 - CO_2 absorber; 13 - safety valve; 14 - vacuum valve; 15 - fan; 16 - automatic pressure regulator; 17 - manual pressure regulator; 18 - shutoff valve; 19 - return valve.

Possible leakage of air out of the cabin due to inadequate airtightness is compensated by compressed air which is supplied from air tanks on board. The oxygen for the crew members is supplied from oxygen tanks (systems) on board.

The main problem in regeneration consists in the maintenance of the required partial pressure of oxygen, removal of carbon dioxide, and excess water vapor. The necessary regime for pressure in such cabins is maintained with the aid of an automatic regulator, and the desired air temperature is maintained with a thermoregulator (cooler, heater).

In pressurized cabins of the regeneration type, the oxygen partial pressure must be 125-160 mm Hg, the partial pressure of carbon dioxide must be 7 - 8 mm Hg at most (0.5 - 1% of the total barometric pressure), the relative humidity of the air must be 30 - 70% and the rated amount of oxygen for one crew member is about 30 liters/hr.

In cabins of this type, the crew may fly without additional oxygen equipment, i.e., they do not use oxygen equipment.

Regeneration type cabins are not yet used in practical aviation.

Pressurized cabins of the oxygen-ventilated type. A cabin of this type is a combination of the ventilated and regeneration types of cabins. The total barometric pressure in them is maintained with the aid of a compressor, while the partial pressure of oxygen is produced by increasing its percentile content by admitting oxygen from tanks on board. At low altitudes, these cabins work like ventilated ones, but at high altitudes they work like oxygen-ventilated cabins.

Oxygen-ventilated cabins differ from the regeneration type by the fact that the carbon dioxide and excess moisture are removed from the cabin air, not by means of chemical absorbers, but by ventilating the cabin with air supplied from a compressor or with oxygen supplied from tanks on board. The excess air (oxygen) as well as the carbon dioxide and moisture are discharged from the cabin into the atmosphere through a regulating valve.

The use of cabins of this type involves a high and unreasonable consump- /122
tion of oxygen. Like the regeneration cabins, they have not yet found applications in aviation.

Hygienic Requirements for Aircraft Cabins

The cabin of an aircraft as a work area for the crew members is defined by the following: its size and design, method of exiting, seat and safety harness, design and location of control devices, instruments and oxygen equipment; the illumination of the instrument panel and the cabin, nature of the view from the cabin, noise and vibration level; temperature mode and chemical composition of the air.

The requirement for creating a maximum possible level of convenience and ensuring acceptable hygienic conditions for the work of the crew in flight are common to all types of aircraft cabins. In addition, the equipment and devices in the cabin depend on the activity of the crew member. Thus, for example, the pilot's cockpit will differ in design and equipment from the navigator's area or that of the gunner-radio operator, etc.

Cabin size. The size of the cabin is very important for normal work of the pilot. In trying to improve the aerodynamic shape of the aircraft, designers usually tend to reduce the cabin dimensions. However, the work of the pilot is made more difficult in a cramped cabin, his movements are restricted, it is more difficult for him to exit from the aircraft in the event of an accident in the air, and it is also possible for him to be injured by accidentally hitting a projecting part while flying or stopping the aircraft.

In the case of multiseater aircraft with a large radius of operation, the cabin dimensions must allow the crew members to move about freely. The cabins of such aircraft must make provisions and provide space for the crew members to rest.

The optimum dimensions of aircraft cabins depend on the extent of the working movements of the pilot, and also on the given anthropometric measurements of the individuals in the flight crew (Table 15, according to V. I. Slesarev, 1958).

TABLE 15

Measurement position	Anthropometric measurements, cm			Tentative measurements with consideration of clothing and special equipment, cm		
	Maximum	Average	Minimum	Maximum	Average	Minimum
Standing height	186.7	170.0	153.3	193.7	177.0	160.3
Seated height	97.6	88.1	78.9	104.6	95.1	85.7
Width at shoulders	52.8	46.2	39.5	66.8	60.2	53.5
Width at pelvis	39.8	34.1	28.5	53.8	48.1	42.5
Width at elbows	59.2	50.5	41.8	79.2	70.5	61.8
Measurement of chest from front to back	25.7	21.3	16.9	38.7	34.3	29.9
Measurement of abdomen from front to back	30.9	23.6	16.3	44.9	37.6	30.3

In determining the width of the aircraft cabin, it is necessary to consider the maximum width of the pilot's shoulders in his suit (special equipment), as well as the need to provide the required freedom of movement. As practice has shown, it is most advantageous to make the cabin no less than 80 cm wide (between the cabin walls).

On calculating the height of the cabin, the distance from the floor level to the highest point in the canopy, the basis is the maximum height of the pilot in a sitting position (98 cm) and the required seat height (about 30 cm). The height of the cabin for a pilot in a pressurized helmet (considering the required space between the canopy and the pilot's head) must be at least 142 cm (single-seater aircraft).

In multi-seater military and civilian aircraft, the height of the cabin must be at least 170 cm. It is recommended that steps be provided for the convenience of short crew members.

The lengthwise dimension of the cabin, the distance from the back of the seat to the instrument panel, must be such that the pilot can be in a comfortable working position and see the instrument panel clearly. The further the instrument panel is located from the pilot, the more instruments will lie in his field of vision. However, making the distance too great will complicate observations of the instrument readings, forcing the pilot to strain his eyes. It has been determined experimentally that it is most convenient to locate /124
the instrument panel 70 to 80 cm from the center of the back of the pilot's seat.

These dimensions for aircraft cabins are approximate. In reality, however, depending on a great many requirements imposed on the cabin, the purpose of the aircraft and its aerodynamics, they may change somewhat.

The cabin must not contain any unnecessary parts or projections which could cause error or injury during flight, emergency landings, and leaving the aircraft. All projecting parts, equipment, angles and edges in the cabin must have a soft shock-absorbing covering.

Pilot's seat. The pilot's seat is the central device in the aircraft cabin. It has a back and seat which resemble a chair, headrest and armrests. All of the instruments, special equipment, controls for the aircraft, etc., are located relative to the seat. The seat must satisfy the following requirements:

— correspond to the nature of the work of each crew member;

— correspond to the dimensions of the body;

— provide convenience in controlling the aircraft, working the controls, and also monitoring the air and instruments;

— not causing excessive fatigue;

— promote increased resistance of the organism to the action of acceleration and overstress;

— make it possible to leave the aircraft reliably and safely.

The position of the pilot which is convenient for work, in which he undergoes the least muscular stress and can withstand the action of overstresses (acceleration) most easily, is shown in Figure 26. As we can see from the figure, in this case his trunk must be tilted slightly backward. It is best to have it tilted at an angle of 16 to 18°.

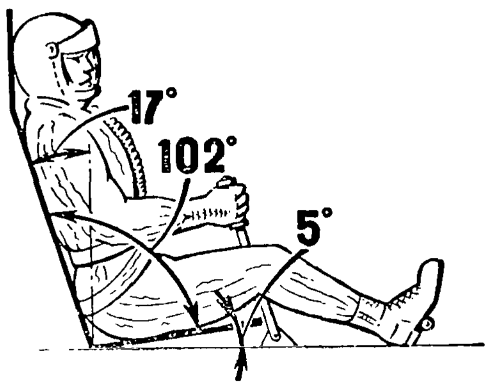

Figure 26. Correct position for pilot in seat.

The width of the chair seat is calculated on the basis of the maximum width of the human pelvis with some allowance for clothing. It is equal to 40 - 45 cm on the average. The cushion on the seat usually has a depth of /125 38 - 40 cm. If the seat is equipped with a parachute, the dimensions and shape of the seat must correspond to the dimensions and shape of the folded parachute. In some types of aircraft, the parachute is located behind the chair back in a special container.

The shape of the chair back must correspond to the correct position of the spine, while the height and width of the back must provide a convenient position for the pilot in his seat. The bottom, back, and head rest should be covered with a soft shock-absorbing material, so as to make the seat conform more readily to the shape of the pilot and eliminate the pressure of metal parts against his body.

The height of the seat mounting relative to the floor of the cabin at the distance from the pedals to the seat can be adjusted depending on the height of the individual. The legs should be slightly flexed at the knees during flight. This prevents rapid fatigue and disruption of blood circulation.

In aircraft which have a long flight duration, the seats of the crew members must be as comfortable as possible, not only for work but also for brief rest in flight.

The majority of modern military aircraft are equipped with special ejection seats, intended for leaving the aircraft under emergency conditions. /126
The control of all ejection processes must be provided by a single assembly which is activated by a single movement of the hand with little force. This is one of the most important requirements imposed on the design of such seats.

Ejection seats must have devices which protect the individual against the influence of the airflow which he strikes when leaving the aircraft at great heights, and must also have stabilizing devices preventing rotation of the chair in the air.

The chair for each crew member has a harness system consisting of shoulder and lap belts and buckles. The belts may be up to 60 mm wide. Their length is adjusted depending on the height of the individual. Safety belts hold the pilot in the seat and prevent him from striking the instrument panel or other equipment in the cabin during sharp deceleration (belly landings) and negative overloads. The chest belts are firmly fastened to the back of the seat at the level of the shoulder blades, while the lap belts are fastened at the level of the sacrum. They must not restrict the movement of the pilot. The fastening part is the buckle which holds all the ends of the belts. The buckle must open and close simply and easily. The design of the buckle and the safety belts is standard on all types of aircraft. At the present time, the majority of ejection seats are equipped with a combined belt system, i.e., a system which constitutes a single whole with the belt system of the parachute.

Control devices and instruments. The control handle of the aircraft (wheel) must not hide instruments at any position. With the wheel fully tilted, the distance between its upper edge and the back of the chair must be at least 35 to 38 cm.

Considerable attention must be paid to standardization of the location of aircraft controls in the cabin, as well as instruments and other parts. Failure to observe this requirement makes the learning process more difficult, complicates the work of the crew members, and may be the cause of an accident in flight.

Control elements of the aircraft, switches and toggles, must be of sufficient size and have a shape that is convenient for operation; they must be placed in readily accessible locations and the direction of their deflection should coincide as much as possible with the direction of aircraft motion. /127
All of their movements must be simple and not require great force.

We know that the cabin of a modern aircraft contains a great many instruments and all manner of different sorts of equipment (pilot, pilot-navigator instruments, instruments for monitoring the operation of the power plant, radio and radar equipment, oxygen instruments, etc.). It is natural that watching the readings on such a large number of instruments and working with the equipment calls for a considerable amount of attention and experience from each crew member.

The principles of the location of devices and equipment in the cabin have been worked out on the basis of the combined experience of designers, pilots, and aviation doctors. In order for the pilot to be able to concentrate his attention on the principal instruments, these instruments are usually located in positions that are readily accessible for observation. Those instruments which are used rarely must be located such that they do not distract the pilot's attention. Instruments of this kind may be equipped with light or sound signals, so that they will attract his attention when necessary.

In the course of many years of flying practice, the following arrangement for instruments has been worked out: The principal piloting-navigation instruments, regardless of the type of aircraft, are located in the left and central areas, while those instruments which control the engine operation are located on the right hand side of the instrument panel. The instruments which monitor the operation of other assemblies are on the control panels on the left and right sides of the cabin.

The instrument panel must be as visible to the pilot as possible. For this purpose, it is mounted at right angles to the longitudinal axis of the aircraft. In order to avoid errors in reading, the distance between the lower edge of the instrument panel and the level of the space below the pedals must be at least 45 cm. The instruments themselves need not project out of the instrument panel.

In the cabin of a multi-seater aircraft, a great many of the instruments and a large part of the equipment must be mounted so that it is visible to the navigator, flight engineer, and gunner-radio operator.

The shape, size, and color of aviation instruments, as well as the /128
graduations on their scales, must allow their readings to be determined quickly

and correctly. As studies have shown, it is most desirable to color the instruments flat black, while the graduations (divisions) on the scales of small instruments should be marked with lines 0.8 - 1 mm wide, while on the scales of larger instruments the lines can be 1.2 - 1.5 mm wide.

Successful analysis of the problems of efficient location of instruments and equipments in aircraft cabins, methods of effectively indicating the instrument readings, signaling abnormal modes of operation of the power plant and the various assemblies, emergency situation in flight and other problems involved in ensuring maximum convenience and required hygienic conditions for the work of the flight crew in the air may be accomplished only by the joint efforts of aviation engineers, doctors, and pilots.

Illumination of the cabin. Windshield. The nature of the cabin illumination is extremely important.

During the day, natural light is completely adequate for normal work in the cabin. Under certain conditions (for example, when flying on a bright sunny day over an area covered with snow) it is even necessary to reduce the intensity of the illumination by using protective shutters and light filters. On night flights, however, it becomes necessary to use artificial light in the cabin.

The illumination of the instrument panel and the instruments, regardless of the type of illumination system used, must be uniform, and its intensity must be continuously adjustable. The construction and location of illuminating devices must exclude the possibility of blinding the pilot and causing light reflections on the glass of the instruments and the canopy of the cabin.

Illumination of work areas for the crew members must be sufficient for easy reading of the instruments, reading the inscriptions on templates and flight charts and must also be sure not to cause deterioration of the conditions for visually observing the surrounding conditions.

An important condition for flight safety and successful performance of flight tasks is a good view out of the aircraft cabin. The glass of the windows must not distort the general shape of objects observed and must be transparent. /129

In horizontal flight, the pilot must be able to have a view out of the aircraft cabin which allows the following: looking forward and down from the skyline (through the nose of the aircraft) in a sector of no less than 15°, down to the side and down to the forward hemisphere, in a sector of no less than 35°, down along the wing in a sector of 8° as well as complete visibility in the upper and rear hemispheres.

Noise and vibration. We know that noises (sounds) and vibrations of certain intensities can have an unfavorable influence on man. Therefore, the aircraft cabin must provide certain requirements for the permissible levels of noise and vibration.

Noise acts as a specific stimulant to the auditory apparatus. The unit employed for measuring the frequency of oscillations is the hertz (Hz), the frequency at which one oscillation takes place in one second.

The human ear can detect acoustic oscillations in the air at frequencies from approximately 20 - 20,000 Hz. Oscillations with a frequency less than 20 Hz are called infrasonic, while oscillations with frequencies above 20,000 Hz are called ultrasonic. Infrasonic and ultrasonic vibrations are not detected by the human ear.

The intensity of sound is measured in the amount of sound energy (in ergs) striking 1 cm^2 of surface per second ($erg/cm^2 \cdot sec$).

Noise consists of a combination of sounds which rapidly change in frequency and intensity. The intensity of noise is measured with special devices called noise meters and is usually expressed in decibels (db). The frequency spectrum of noise is very important in characterizing it, i.e., the oscillation frequency of the sounds that form the noise.

The principal sources of aviation noise are the power plant of the aircraft (the engine and its assemblies) as well as the aerodynamic resistance of the airflow (aerodynamic noise). During the flight of a supersonic aircraft, aerodynamic noise may amount to 95% of the aviation noise.

The noise intensity of a piston engine operating on the ground reaches 150 - 120 db (at a distance of 5 m from the propeller), while that of a jet engine reaches 150 db and more. The maximum noise intensity is found at the rear and side parts of the aircraft. In the aircraft cabin, the noise inten- /130
sity drops to 80 - 100 db (depending on the type of aircraft and the effectiveness of the sound insulation in the cabin). The greatest amount of noise reduction is achieved in pressurized cabins, which have sound insulating coverings. In gerneral, however, during operation of the engine without the afterburner, the noise level in the cabin will not exceed 90 db, while the noise rises to 100 db when the afterburner is cut in.

The influence of noise on the human organism depends primarily on its intensity and length of action, as well as on its frequency spectrum. The more low frequencies in the noise, the greater its fatiguing action; the more high frequencies there are, the greater its painful effect on the auditory apparatus.

The biological effect of ultrasound and infrasound on man has been studied comparatively little, but experimental data are available which indicate that they do have a traumatic effect on the organism. Particularly unfavorable effects are created by infrasound.

Noise at high intensity not only can cause a deterioration of hearing, but also has an unfavorable effect on the organism, especially the central nervous system. Under the influence of noise of this kind, the activity of the respiratory organs may be disturbed, and the cardiovascular system as well as the gastrointestinal tract may be affected; the acuity of vision will decrease, sleep will be disturbed, attention will be distracted, fatigue will increase, psychic reactions will slow down, and working ability will deteriorate.

Noises with an intensity of less than 80 db will not disturb the working ability of human beings, but at noise intensities from 80 - 100 db there is a decrease only in certain individuals, since most persons have sufficient capacity for physiological adaptation to noises of this kind. A constant noise will cause less of an influence on the organism than an interrupted one. As the intensity of the noise increases, its unfavorable influence on the working ability and condition of the organism likewise increase. Noise with an intensity of approximately 130 db will cause painful sensations. Such a noise level is called the threshold of painful sensitivity. Noises with an intensity of 150 db cannot be withstood by human beings, while noises with an intensity /131
of 160 db can cause rupture of the eardrums and damage to the inner ear.

If the human ear is subjected for a sufficiently long time or periodically to repeated action of a loud noise, temporary or permanent hearing loss may result. The resistance of individuals to the effect of noise is not uniform.

Noise with an intensity of 90 db, acting on an individual for 6 - 8 hours, will cause a moderate degree of hearing loss. In this case, hearing is restored about an hour after the noise ceases. After several hours under conditions of noise with an intensity of 115 db, an individual will gradually lose the ability to detect noises in the middle and high frequencies (from several minutes to several days). Noise whose intensity exceeds 120 db causes fatigue within 10 - 15 minutes as well as a significant loss of hearing.

Studies have shown that the intensity of noise near a jet aircraft with engines operating is so high that there is danger of injury to the hearing organs for the unprotected ear. It is primarily the engineering and technical crews who are exposed to the action of noise at such intensities, since they are exposed to these conditions when preparing aircraft for flight. In the majority of these types of aviation specialists (especially those who have worked for more than ten years), there is progressive loss of hearing over a wide range of the frequency spectrum and especially at frequencies of 3,000 - 4,000 Hz.

The members of the flight crew are subjected to the action of noises of high intensity to a lesser degree, since there is less need for them to enter zones of strong noise at the airfield, while during flight they are protected against the noise by the sound insulation of the pressurized cabin, as well as their helmet earphones or pressurized helmets. A slight loss of hearing in these people is most often noticed after five to six years of work, especially those who have deficiencies in the organs of the ear, nose, and throat.

Preventing unfavorable influence of noise. At the present time, the following are used to combat aviation noise:

— special devices which reduce the noise intensity of source itself;
— effective sound insulation of aircraft cabins; /132
— noise-protecting equipment for damping engine noise when working on the ground;
— collective and individual noise-protecting devices for the crew;
— limiting the time under noisy conditions and organizing a proper work schedule.

Equipment for protection against noise includes movable and stationary absorbers. Movable absorbers are hollow metal cylinders which are mounted in front of and behind the aircraft; stationary absorbers are tunnels or boxes in which the tail section of the aircraft is enclosed, as well as concrete enclosed hangars. Noise-protecting equipment is used also as a collective method of protecting the crew checking out operating motors.

Of all the methods for protection against noise, it is most convenient to use helmets which cover the ears and the area around the ears, as well as earphones and earplugs. Helmets and earphones reduce the noise level to 25 - 30 db.

Under the conditions prevailing at airfields, in order to avoid damage from engine noise, it is recommended that persons who are in front of an aircraft should be 150 - 250 m away; those located to the right and left should be 600 - 1,000 m away, and those who are behind should be 1,000 - 1,500 m away.

One of the important measures taken to protect the flight and engineering technical crews against noise injury is the establishment of admissible intensities, operating times, and frequency spectra for the noise. Table 6, compiled on the basis of test data, shows the admissible values of intensity and duration for action of aviation noises which should not be exceeded in daily operation.

TABLE 16

Noise intensity, db	100	110	115
Duration of action, hours	6	1	0.5

The standards shown in this table refer to noises with a frequency spectrum from 150 - 3,000 Hz. The same values apply to the aircraft cabin. /133

As we have already mentioned, aside from noise, the human beings in an aircraft are also subject to vibration. Vibration is characterized by direction, amplitude, and frequency. In aviation practice, we most frequently encounter vibration in the vertical and horizontal directions in a frequency range from 10 - 50 Hz at an amplitude up to 1 mm. Aircraft vibrations have the nature of complex periodic oscillations. Their sources are operating engines and the effect of the relative wind.

The greatest effect on man is caused by vertical vibrations. In an aircraft, it is considered permissible (as far as action on man is concerned) to have vertical vibrations which have: (a) frequency up to 10 - 20 Hz and amplitude up to 0.8 mm; (b) frequency up to 30 Hz and an amplitude of 0.4 mm; (c) frequency of 40 - 60 Hz and amplitude of less than 0.4 mm.

Practically speaking, the vibrations which develop in ordinary flight have characteristics whose values do not exceed the permissible limits.

Resistance of individuals to the action of vibrations is different: some withstand it well, others become fatigued rapidly. There are special antivibration devices aboard aircraft which make it possible to a considerable degree to reduce the intensity of the vibrations or to get rid of them entirely.

Temperature regime. As we have already pointed out, providing a regular temperature regime is one of the basic hygienic requirements for an aircraft cabin. It also governs the so-called thermal state of the organism.

The retention of a normal thermal state of an organism is of tremendous importance for the health and working ability of man.

Constant body temperature is maintained by regulatory mechanisms that are under the control of the central nervous system. When the temperature of the external medium drops, oxidation processes in the organism become more intense, increasing the consumption of oxygen and reducing the loss of heat. However, when the temperature increases, the intensity of oxidation processes in the organism decreases and heat loss becomes more severe.

Heat loss takes place as a result of radiation of heat by the surface of the skin, conduction, evaporation of perspiration and respiration. /134

The organism loses 40 - 45% of its heat on the average through radiation. If at a sufficiently high temperature of the medium, objects with a lower temperature are located near the individual, the heat loss by radiation will increase. Such a phenomenon may be observed during high-altitude flights if the aircraft cabin does not have sufficient heat insulation. In such instances, the pilot may feel cold even at an air temperature in the cabin of +15 - 16° C. When the temperature of the surrounding air and the objects becomes equal to body temperature or exceeds it, heat loss by radiation ceases.

The human organism loses heat through conduction if the temperature of the surrounding air is lower than the temperature of the body. Naturally, the lower the temperature of the medium, the greater the heat loss.

A significant amount of heat is lost through evaporation of perspiration from the surface of the skin and with the expired air. The magnitude of these losses depends primarily on the temperature, the humidity of the surrounding air, and the rate of its movement around the body. At an air temperature and temperature of objects surrounding an individual equal to +37° or more, heat loss takes place only through the evaporation of sweat.

Due to the improvement of devices for regulating the body temperature, man can now withstand very significant variations of temperature in the surrounding air. Thus, observations have shown that an individual can survive for 23 minutes without particular damage to himself at a dry-air temperature (not containing water vapor) equal to +116° C; a warmly dressed individual can withstand extremely low temperatures (down to -88.3° C) for a long time.

As the moisture in the air decreases, its heat capacity and heat conductivity increase considerably. Hence, the range of temperatures which man can withstand is sharply reduced.

Although the human organism has the ability to withstand very high and very low ambient temperatures, this does not mean that temperature has no effect upon it. Both high and low ambient temperatures with sufficiently long exposure, will have significant deteriorating effects on working ability and will increase fatigue. A temperature of $+15 \pm 5^{\circ}$ C is considered average for aircraft cabins. A temperature of +18 to 20° C is considered most favorable for the human organism. Such a temperature is conducive to increasing the resistance of the organism to the action of all flight factors and particularly resistance to the action of reduced barometric pressure, acceleration, etc.

The difference in air temperature at various points in the cabin on the horizontal (along the cabin) must not exceed 5° C, 3 - 4° C in the vertical direction, since it is desirable that the air temperature at the floor of the cabin be somewhat higher than in the upper zone (at the level of the pilot's head). More significant temperature differences within the cabin may cause colds.

The temperature of the cabin walls must not differ from the air temperature in the cabin by more than 3° C, since otherwise the individual will undergo high heat loss as a result of radiation.

For heating a pressurized cabin of the ventilated type, as well as creating the required excess pressure and ventilation, air is obtained from a compressor. This air, during compression in the compressor, is heated to 250 - 270° C and passes through a system of ducts to reach the lower and upper zones of the cabin. To regulate the temperature and the amount of air entering the cabin from the blower system, modern aircraft have air-air radiators, a turbocooler, a regulator for air feed to the cabin and a thermostat.

During the flight, there is a continuous leakage of heat out of the cabin. To reduce the heat losses, the walls of the cabin and the pipes in the blower system are covered with a layer of insulation (fiberglass or wool, soaked in nonflammable substances), 4 - 17 mm thick. This layer simultaneously acts as sound insulation.

Thanks to the thermal insulation and correct distribution of the warm air coming from the compressor, temperature conditions are created in the cabin which conform to hygienic requirements.

In some types of aircraft, heating the cabin solely by means of the air coming from the compressor is inadequate. In this case, special electrical heaters are used for additional heating. They are used at low air temperature /136
in the cabin and when the glass frosts over. An electrical heater constitutes an electrical air-blower furnace with a fan and three sections of heating elements. The electric heater is powered by the electrical system aboard the aircraft. In the event that overheating is possible, the heater automatically shuts off with the aid of a thermoswitch.

At the present time, the problem which is physiologically most important and technically most difficult is that of protecting the pilot against overheating, especially during flights at low altitudes and in hot climates. This problem is solved successfully by using air-conditioning.

The air-conditioning system (air conditioner) consists of a cooling turbine, heating devices, and automatic temperature-regulating mechanisms. The air-conditioner makes it possible to maintain air temperature in the aircraft cabin at any altitude at levels which conform to the hygienic norm.

Air humidity. The humidity of the air has a definite physiological effect on the human organism. At low humidity, dryness of the mucous membranes of the eyes and nasopharynx is seen; skin becomes rough and cracks. Other negative phenomena are also observed. High humidity also has an unfavorable effect on man: at high air temperatures, it promotes overheating of the organism, since evaporation of sweat is impeded, while at low air temperature if has a supercooling effect, since moist air increases heat conductivity. In pressurized cabins of the ventilated type, a relative humidity of 40 - 60% is considered most favorable; a relative humidity of 20% is the average norm, and the minimum level is 15%. In cabins of the regeneration type, the relative humidity must be 30 - 70%.

The thermal state of an individual is largely dependent on the rate of air movement. When this rate is increased, heat loss is decreased. At low temperatures, air flow promotes rapid cooling of the body. At high temperatures, blowing air over the body improves the feelings of the individual and prevents him from being overheated. /137

The rate of air movement in the cabin in any ventilation system and at favorable temperatures and humidity levels in the cabin must not exceed 0.2 m/sec; under less favorable conditions, a rate of 1 - 1.5 m/sec is allowed.

Chemical composition of the air. The condition of the health and working ability of man is significantly influenced by the chemical composition of the air in the aircraft cabin. Therefore, considerable importance is placed on preventing pollution of the air in the cabin. Pollution sources may be vapors from aviation fuel, products of pyrolysis of mineral oils, and other harmful impurities.

To a certain extent, the excess pressure produced in the cabin by an engine compressor acts as a protection against penetration of harmful gases into the pressurized cabin through leaks in its walls. However, together with the air which comes from the compressor, fine particles of oil (oil fog) may enter the cabin, as well as vapors of kerosene and benzene, decomposition products of mineral oil (acroleins and aldehydes) and carbon monoxide (exhaust gas). Exhaust gas is the most dangerous.

The toxic effect of carbon monoxide (CO) is great. Man begins to feel its toxic effect at concentrations as low as 0.07 - 0.1 mg/liter of air. However, individual sensitivity of persons to the effect of exhaust gas is very different. At concentrations of 0.22 mm/liter, slight pains are felt after two to three hours in the area of the forehead and temples. As the CO content in the inspired air increases, the poisoning effect increases rapidly as well. Thus, the lethal outcome may develop as follows: at a concentration of 1.26 - 1.72 mg/liter, in 1.5 - 3 hours; 2.3 - 3.4 mg/liter, 30 - 45 minutes; 5.7 - 11.5 mg/liter, 2.5 minutes; 14.08 mg/liter, 1 - 3 minutes; 20 - 25 mg/liter, several seconds.

Carbon monoxide primarily affects the central nervous system. Carbon monoxide poisoning may be mild or serious. Mild poisoning is accompanied by headache, dizziness and general weakness. Sometimes fatigue and nausea are observed. In serious cases, loss of consciousness may result, with spasms and death. The essence of the action of carbon monoxide consists in the fact /138 that it enters into a chemical reaction with the blood hemoglobin. As a result of the reaction, a resistant chemical substance (carboxyhemoglobin) is formed which cannot combine oxygen and supply it to the tissues. Consequently, in cases of carbon monoxide poisoning, the supply of oxygen to the tissues by the blood is disrupted, which causes them to suffer from oxygen starvation.

Staying under conditions of reduced partial pressure of oxygen while breathing air that contains carbon dioxide considerably increases the effect of oxygen insufficiency on the organism; the working ability of the individual is disrupted to a large extent. Therefore, it is necessary to take all measures that will exclude any possibility of carbon monoxide penetrating the cabin of the aircraft. A factor which is very important in this regard is timely performance of maintenance work on engines.

Breakdown of mineral oil takes place under the influence of high temperatures to which parts of aircraft engines are exposed. A number of gases harmful to the organism are formed in this process. The most important is acrolein, which, as mentioned earlier, causes irritation of the mucous membrane of the upper respiratory tracts and eyes. At the same time, formaldehyde and unsaturated hydrocarbons may be formed, which have both a general and local irritating effect. The limit of permissible concentration (in mg/liter of air) of acrolein in cabin air is 0.002, while the formaldehyde level is 0.005 mg/liter.

As we have already mentioned, benzene and kerosene vapor can also penetrate the cabin. The limit of permissible concentration of benzene and kerosene vapor is 0.03 mg/liter.

Powder gases, as well as carbon monoxide, also contain nitrous oxides. The limit of permissible concentration of nitrous oxide in the cabin air is 0.005 mg/liter.

In some older types of aircraft, exhaust gases can penetrate the cabin which contain lead and its compounds in addition to carbon monoxide. The limit of permissible concentrations of lead and its compounds in cabin air is 0.001 mg/liter, while the carbon monoxide level is a maximum of 1%.

These limits of permissible concentration levels of toxic substances are given without consideration of their total effect on the organism. In the /139
total effect, the poisoning effect of the substances is increased many fold.

To prevent penetration of harmful impurities into the cabin along with the air that comes from the compressor, the pipes are fitted with absorbing filters. In addition, in order to prevent the possible accumulation of harmful impurities, continuous ventilation of the cabin is practiced, as we have already said. As a result, the chemical composition and physical properties of the air are normalized, i.e., conditions are created which are favorable for vital activity of the pilot.

As we already pointed out in Chapter II, with increasing altitude the ozone content increases. This gas has highly toxic properties. At altitudes of 45 - 50 km, we find the maximum concentration of ozone, which does not exceed 0.000004%. However, in the inspired air, a concentration of 0.00001% (0.0001 mg/liter) is considered to be the maximum allowed. According to the data of the French scientist Bizet, ozone becomes toxic if it is contained in air in an amount of 0.0003% (0.003 mg/liter). At higher concentrations, ozone will have a harmful effect, primarily on the respiratory organs.

Ozone is an unstable chemical compound that breaks down readily at a temperature of +250 - 300° C. Therefore, on entering the blower system of a pressurized cabin together with outside air, ozone breaks down under the influence of high temperatures in the turbocompressor. In addition, at high altitudes the pilot uses oxygen supplies, so that his respiratory organs are completely isolated from the surrounding atmosphere. Therefore, even if it should get into the cabin, the harmful effect of ozone on the organism is prevented.

Hence, for flight crews of modern aircraft, ozone is a negligible danger.

Flights at high altitudes must be accompanied by determination of the effect of cosmic radiation and solar radiation on the crew. In addition, during any flight, the crew members are subjected to the action of ionizing radiation, whose sources are various devices and radio apparatus mounted aboard the aircraft. The daily dose of natural radiation which an individual receives under ordinary conditions on Earth amounts to 0.4 - 2 mrem[8]. /140
This dose is made up of external and internal radiation. The former consists of cosmic and solar radiation as well as terrestrial gamma radiation, while the second consists of radiation from radioactive elements in the organism in small amounts. The human organism has become accustomed to this dose of radiation during its evolutionary development.

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[8] The rem (biological roetgen equivalent) is the amount of any form of radiation equal in its biological action to 1 roetgen: mrem = 0.001 rem.

However, at the present time, various radioelectronic devices have come to be used in science and technology which are sources of ionizing radiation. When working with them, personnel must be exposed to radiation at much higher doses than the dose of natural radiation, and which sometimes are dangerous for health. Therefore, on the basis of scientifically based health rules and procedures for individuals constantly working with sources of ionizing radiation, a maximum admissible dose of professional radiation has been established. This standard is also applicable to aircraft cabins.

We know that, as altitude increases, the intensity of cosmic radiation increases. The dose of radiation at the altitudes reached by modern aircraft does not exceed the permissible radiation limit. However, if we consider that the flight time of aircraft at high altitudes is very limited, there is no basis for fearing any kind of harmful biological effect of cosmic radiation under such conditions. An exception in regard to danger of biological effects might be posed by flights at these altitudes during chromospheric flares on the Sun, when the intensity of ionizing radiation increases sharply. However, such flares occur rarely.

CHAPTER VI

PHYSIOLOGICAL-HYGIENIC FUNDAMENTALS OF OXYGEN EQUIPMENT

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The oxygen equipment used aboard modern military aircraft constitutes a method of increasing the partial pressure of oxygen in the inspired air. This is necessary in those cases when the partial pressure of oxygen cannot be raised to the required level by increasing the barometric pressure in a pressurized cabin, and also in the event of accidental decompression of the cabin at high altitudes or on parachuting from the aircraft.

The components of the oxygen equipment consist of the aviation oxygen devices and the high altitude equipment.

Aviation Oxygen Devices

Depending on the method of supplying the oxygen, there are three types of aviation oxygen devices:

(1) Devices with continuous oxygen feed; these devices supply oxygen both during inspiration and expiration;

(2) Devices of the "pulmonary automatic" type with periodic oxygen feed; oxygen is supplied only during inspiration by devices of this kind; admission of oxygen beneath the mask is regulated by breathing;

(3) Devices of the "pulmonary automatic" type for breathing oxygen under increased pressure; these devices operate up to 12,000 m as devices of the "pulmonary automatic" type, but above 12,000 m oxygen is supplied to the respiratory tracts of the user under pressure greater than that of the surrounding atmosphere.

Aviation oxygen devices are also characterized by their purpose. Three groups can be defined when this system is used: /142

(1) Onboard stationary oxygen devices, intended to supply oxygen to the crew members at their working stations and installed in the aircraft cabin, with one device provided for each crew member;

(2) Onboard portable oxygen devices, used to supply oxygen to the crew members while moving about the aircraft;

(3) Parachute oxygen devices, used to provide oxygen to crew members when descending by parachute from great altitudes in the event of an accident in the air or for sport.

All oxygen devices must provide automatic regulation of oxygen feed with altitude, minimum resistance to inspiration, and minimum weight and size. They must be simple and reliable to use.

Oxygen Devices with Continuous Oxygen Feed

Devices with continuous oxygen feed (Figure 27) consist of onboard stationary devices installed primarily on aircraft designed for flying at altitudes below 12,000 m as well as portable and parachute devices. Devices of this type are designed for individual and collective use. Oxygen feed in them increases with altitude and is automatically regulated with the aid of an aneroid device. They operate together with masks of the open or semi-open type (with additional capacity).

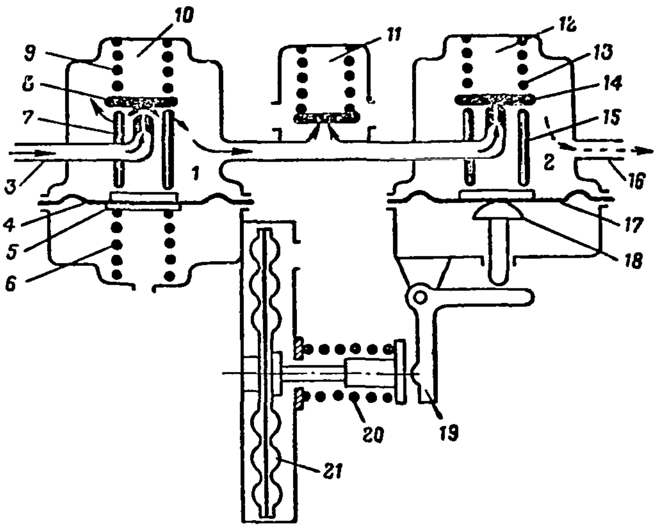

Figure 27. Schematic diagram of device with continuous oxygen feed:

1, 2 - reducing valve chambers; 3 - inlet pipe; 4, 17 - membranes; 5 - disk; 6, 9, 13, 20 - springs; 7, 15 - plungers; 8, 14 - slide valves; 10 - high-pressure reducing valve; 11 - safety valve; 12 - low-pressure reducing valve; 16 - outlet pipe; 18 - rod; 19 - lever; 21 - aneroid chamber.

The oxygen mask of the semi-open type has additional capacity in the form of a rubber bag connected to the space beneath the mask. The bottom of the bag is provided with an opening that can be opened and closed (using a special plug) to remove moisture that is formed during respiration as the result of water vapor condensation. The additional capacity means that the oxygen is consumed more economically and the user obtains better results at high altitudes. A mask of this type must fit very closely to the face; otherwise outside air will be drawn in. This means that every pilot must carefully put on the mask and strap it to his face.

After each use, the mask must be carefully wiped and dried. /143

Masks of both the open and semi-open type have openings through which the space beneath the mask communicates with the atmosphere. This means that atmospheric air is drawn in together with pure oxygen when the user of the mask draws a breath. As a result, the oxygen mixes with the air which the individual breathes. The oxygen content in this mixture depends on the amount of oxygen supplied beneath the mask and the depth of respiration. When the flight altitude remains the same, the amount of oxygen also remains fixed; the latter is sufficient for respiration in a state of relative physical rest. However, under conditions of physical and neuro-emotional stress, the depth of respiration (pulmonary ventilation) increases significantly, so that the volume of the air drawn in beneath the mask increases, and the gas mixture contains less oxygen. Finally, the organism begins to suffer from oxygen /144
insufficiency, which may lead to a decrease in working ability. This is the principal shortcoming of these devices.

Another shortcoming of these devices is the uneconomic consumption of oxygen; oxygen is supplied continuously, but used only during inspiration; it escapes freely into the atmosphere during expiration. Hence, more than 50% of the oxygen is wasted. Oxygen devices with continuous oxygen feed have a number of advantages over devices of other types. The most important of them are the following:

— low resistance to respiration;
— convenience of use, simplicity of design, small size of the device, mask and hose;
— insignificant variation in the composition of the inspired mixture with relatively loose attachment of the mask to the face.

Shortcomings of the device are as follows:

— uneconomic use of oxygen because it is supplied during expiration and the pauses between inspiration and exspiration;

— deterioration of oxygen supply to the organism during physical or neuro-emotional stress.

Devices of this kind include stationary oxygen devices KP-22 and KP-32 and parachute devices KP-23 and KP27M.

Oxygen Device KP-22

Oxygen device KP-22 is designed for collective use with continuous oxygen feed. It is installed in transport and passenger aircraft.

It is designed for supplying oxygen to as many as ten individuals simultaneously in flight at altitudes up to 8,000 m; it works in conjunction with a type KM-15 open mask. The oxygen begins to flow beneath the mask beginning at 2,000 m; its supply is regulated automatically depending on altitude and is monitored on a gauge. At an altitude of 3,000 m, a single individual receives 1 liter of oxygen per minute; at 4,000 m, he receives approximately 2 liters and at 8,000 m, 6 liters/min.

The oxygen is supplied from oxygen tanks with a working pressure of /145
150 atm. In case of failure of the automatic oxygen supply provided by the KP-22, it is necessary to use an emergency supply valve.

Oxygen Device KP-32

Oxygen device KP-32 belongs to the same group of devices as the KP-22. It is designed for simultaneously supplying oxygen to as many as 20 individuals in flight at altitudes up to 12,000 m; it is used in conjunction with the KM-19 open-type mask. It is used aboard transport and passenger aircraft.

Oxygen is supplied from onboard tanks; tanks with a maximum oxygen pressure of 30 and 150 atm are used.

Oxygen feed begins at 2,000 m and is regulated automatically depending on altitude. At an altitude of 12,000 m and a temperature of +20° C, an individual will receive a maximum of 7 liters/min of oxygen; at -50° C, he will receive up to 9 liters/min. Feed can be regulated with the aid of a manual regulator and monitored on a gauge. With manual regulation, maximum oxygen feed with connection at 20 points will not exceed 12 liters/min at any one point.

Onboard Portable Oxygen Devices

Portable oxygen devices may have either continuous oxygen feed (KP-21) or may be pulmonary-automatic (KP-19). They are used on military transport and civilian aircraft, as well as special purpose aircraft.

The portable device is mounted on the neck of an oxygen tank. The crew members use these devices in flight at high altitudes when moving about the aircraft.

Parachute Oxygen Devices

Parachute oxygen devices are designed for individual use with continuous oxygen feed. All members of the crew of military aircraft are equipped with them. They are used on parachuting from the aircraft, or if the onboard em
system fails at altitudes of 6,000 - 8,000 m or more. /146

The parachute oxygen device supplies oxygen to the pilot (parachutist): (a) when leaving the aircraft, from the moment of separation from the aircraft and until descent to a safe altitude; (b) in the event the onboard oxygen system fails at high altitudes, from the beginning of failure until the aircraft is brought down to a safe altitude (approximately 4,000 m).

The total supply of oxygen in a parachute device is intended for 10 - 13 minutes of operation.

Parachute oxygen devices are used in conjunction with all staionary onboard oxygen devices of the pulmonary-automatic type, flying suits and pressurized masks (pressurized helmets).

Parachute oxygen devices are simple in design and convenient for use, and are small in size; each device fits into the parachute pack. They do not have reducing valves or oxygen flow indicators. There is no constant standard rate of oxygen feed for these devices. The feed per minute depends on pressure in the small tanks and the length of time the device is used. At the present time, parachute oxygen devices KP-23 and KP-27M are used.

Parachute oxygen device KP-23 (Figure 28) is designed for altitudes up to 14,000 m.

The device consists of a flat metal box containing the following: a battery of small tanks containing oxygen, consisting of 12 cupronickel tanks connected in series having a total volume of 0.825 liters; a switch with a shutoff valve; an MK-14M oxygen manometer; a helical capillary tube with an internal diameter of 0.35 mm to limit the flow of oxygen; a charging connector with a return valve. All parts of the apparatus are fastened by screws to the base and cover.

The oxygen supply in the tanks is 125 liters at a pressure of 150 atm. One minute after the KP-23 device is turned on, oxygen is supplied at a rate of 16 liters/min (after ten minutes, 4 liters/minute).

Changeover of the oxygen supply from the stationary device to the parachute type takes place automatically upon leaving the aircraft.

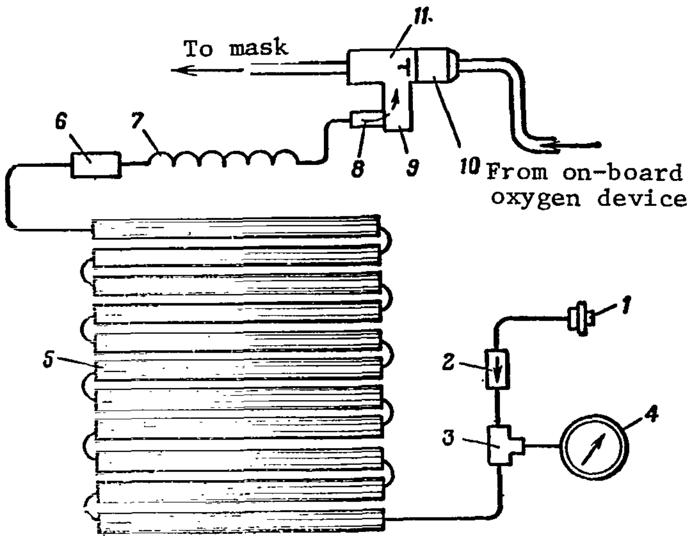

Figure 28. Diagram of KP-23 parachute oxygen device:

1 - charging connector; 2 - one-way valve; 3 - tee connector; 4 - manometer; 5 - small tanks of compressed oxygen; 6 - filter; 7 - capillary tube; 8 - shutoff valve; 9 - switch; 10 - removable lock; 11 - return valve.

In case it is necessary to use the KP-23 device as an emergency oxygen device if the stationary supply fails, the control pins must be withdrawn from the plugs, and an immediate descent to a safe altitude must be made. The K-23 is used with any type of parachute that has a pack to accommodate it.

The KP-27M parachute oxygen device is designed in the same fashion as the KP-23, but unlike the latter, the KP-27M has an additional oxygen tank to rapidly fill the chamber of the tensioning device of the pressurized suit. After these chambers are filled, the excess oxygen passes through the pressure regulator beneath the mask and is used for breathing.

The KP-27M is included in the KKO-1M and KKO-3 systems in flights above 12,000 m. When the pilot ejects, the KP-27M device switches on automatically.

The oxygen supply in the tanks at a pressure of 150 atm is equal to 130 liters. /148

In case the onboard oxygen system fails, or if the oxygen in the onboard tanks is consumed, the KP-27M device is switched on manually. One minute after the KP-27M has been switched on, it supplies up to 60 liter/min of oxygen (after 11 minutes of operation, the flow is reduced to 3 liter/min).

The KP-27M is used with parachutes of any kind.

Oxygen Devices of the "Pulmonary Automatic" Type With Periodic Oxygen Feed

Oxygen devices of the "pulmonary automatic"* type with periodic oxygen feed are the type most widely used in aviation. They are called "pulmonary automatic", because they are activated by the respiration of the user. The impulse which switches on the oxygen feed is a relative rarefaction which develops in the main housing of the device during inspiration. Therefore, such devices, i.e., ordinary pulmonary automatic devices, are only used with closed (pressurized) masks. At altitudes up to 4,000 m, each breath drawn into the respiratory tracts of the user admits oxygen or a mixture of the latter with atmospheric air at a pressure which does not exceed the pressure of the surrounding atmosphere. Exspiration takes place into the atmosphere through an exhaust valve located in the mask which opens on exspiration and closes on inspiration. In contrast to the composition of the gas mixture formed during operation of the device for continuous oxygen feed with masks of the open type, the percentile content of oxygen in the gas mixture supplied by the pulmonary automatic device is independent of the depth and frequency of respiration. It is maintained automatically within the necessary limits, depending on the altitude. As altitude increases, the intake of atmospheric

*Editor's Note: Automatic lung-type breathing equipment (demand oxygen equipment).

air decreases, and the percentile content of oxygen in the inspired gas mixture increases. At 10,000 m, intake of air is completely suspended, and pure oxygen begins to flow from the device into the respiratory tracts. The amount of gas mixture is determined by the depth and frequency of respiration (pulmonary ventilation), which in turn depends on physical stress.

Up to an altitude of 10,000 m, the device maintains a partial pressure of oxygen in the inspired air which is equal to its partial pressure in the atmosphere at sea level (approximately 150 mm Hg). /149

The mask of the oxygen device must fit very closely to the face. Otherwise, due to intake of atmospheric air through leaks, oxygen starvation can develop as low as 6,000 - 10,000 m. In order to exclude the possibility of drawing in air, improved oxygen devices of the "pulmonary automatic" type supply oxygen beneath the mask with a slight (up to 30 - 40 mm water column) excess pressure. The excess pressure (head) is developed by a special mechanism (head mechanism) which begins to operate at altitudes above 4,000 m. As the desired excess pressure of oxygen beneath the mask is achieved, the head mechanism stops the feed. Feed is automatically resumed as soon as the excess oxygen pressure beneath the mask falls below 40 mm water column.

When it is necessary to switch to breathing pure oxygen at altitudes up to 10,000 m (for example, when entering a zone contaminated by radioactive and poisonous substances, bacterial agents, or for purposes of desaturating the organism with respect to nitrogen) the mechanism for drawing in atmospheric air is shut off manually.

The advantages of the "pulmonary automatic" type of apparatus include the following: economic consumption of oxygen and the possibility of using pilots' gas masks (sealed masks).

The shortcomings of devices of this type include the following: resistance to inspiration (up to 60 mm water column) which develops because, in order to operate the device, it is necessary first of all to develop a corresponding rarefaction in it; complexity of operation (in comparison to the operation of devices with continuous oxygen feed), since more accurate handling is required; individual fitting of the mask and constant attention to the tightness with which it is attached, training the flight crew to become accustomed to the use of the device.

System of KP-18K Oxygen Device /150

In addition to the KP-18K device itself, the system includes the following: KP-23 parachute device, oxygen mask KM-16A, oxygen hose KSh-10, indicator IK-18, reducing valve KR-14A, and onboard oxygen fittings KAB-14.

The KP-18K oxygen device (Figure 29), designed for individual use, operates on the "pulmonary-automatic" principle; the oxygen is supplied period- /151 ically (only during inspiration) at a low excess pressure (head). The percentile content of oxygen in the gas mixture is regulated automatically, depending on altitude.

The KP-18K device is intended for supplying the pilot with oxygen at altitudes up to and including 12,000 m.

The gas mixture supplied by the device at 4,000 m contains 35 - 55% oxygen (55 - 92% at 7,500 m, 90% or more at 8,500 m).

The average rated normal level of oxygen flow at altitudes up to 8,000 m is 6 liters/min, while above 8,000 m it is 10 liter/min.

In case the head mechanism should fail or the "pulmonary-automatic" oxygen supply should not operate correctly, oxygen can be obtained through an emergency valve opened manually.

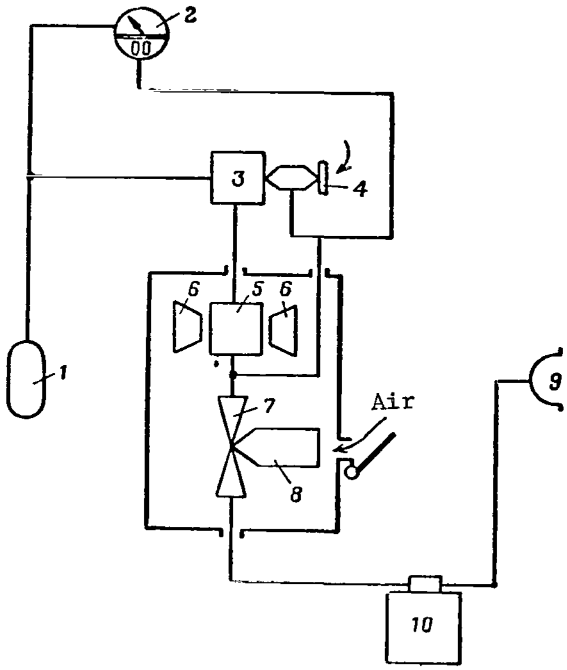

Figure 29. Diagram of KP-18K oxygen device:
1 - oxygen tank (150 kgf/cm^2); 2 - IK-18 oxygen indicator;
3 - reducing valve (10 kgf/cm^2); 4 - emergency valve;
5 - pulmonary automatic device; 6 - head system;
7 - ejector; 8 - automatic air inlet; 9 - oxygen mask
(KM-16A); 10 - KP-23 oxygen device.

To check the operation of the KP-18K, the IK-18 indicator is used, which consists of a manometer and an oxygen indicator.

Oxygen Devices of the "Pulmonary Automatic" Type for Breathing Oxygen Under Excess Pressure

Flights at altitudes above 12,000 m with ordinary oxygen devices of the "pulmonary automatic" type are possible aboard aircraft with pressurized cabins, in which the pressure is maintained higher than in the surrounding atmosphere.

However, in the case of cabin depressurization at these altitudes, the pilot will undergo severe oxygen insufficiency (oxygen starvation), which can lead to a rapid loss of consciousness. As we have already mentioned, this is caused by the atmospheric pressure being too low at these altitudes; consequently, there is low partial pressure of oxygen in the inspired and alveolar air. Thus, for example, at 13,500 m the partial pressure of oxygen in the alveolar air when breathing pure oxygen drops to 40 mm Hg, i.e., approximately to the value of the partial pressure of oxygen when breathing atmospheric air at an altitude of 5,000 m. Such a partial pressure of alveolar oxygen is insufficient for normal saturation of the blood with oxygen. In order to allow the organism to attain the required amount of oxygen at altitudes above 12,000 m, it is necessary to increase the pressure of the oxygen being supplied. To do this, types of devices of the "pulmonary automatic" type are employed for breathing oxygen under excess pressure (Figure 30).

Oxygen devices of this type supply pure oxygen to the mask at altitudes /152
above 12,000 m under pressure which exceeds atmospheric at flight altitude. This means that the partial pressure of the oxygen in the alveolar air is increased, and its saturation in the arterial blood is improved. Thus, for example, when breathing pure oxygen at 15,000 m at an excess pressure beneath the mask of 20 - 25 mm Hg, the partial pressure of oxygen in the alveolar air /153
reaches 45 - 60 mm Hg. This makes it possible for the pilot to retain satisfactory working ability for a short period of time. The mask of the oxygen device with excess pressure must be very carefully fitted to the face and lie tightly against it. In the case of a poor fit of the mask, it is difficult to develop the required excess pressure beneath it and to achieve an economical consumption of oxygen.

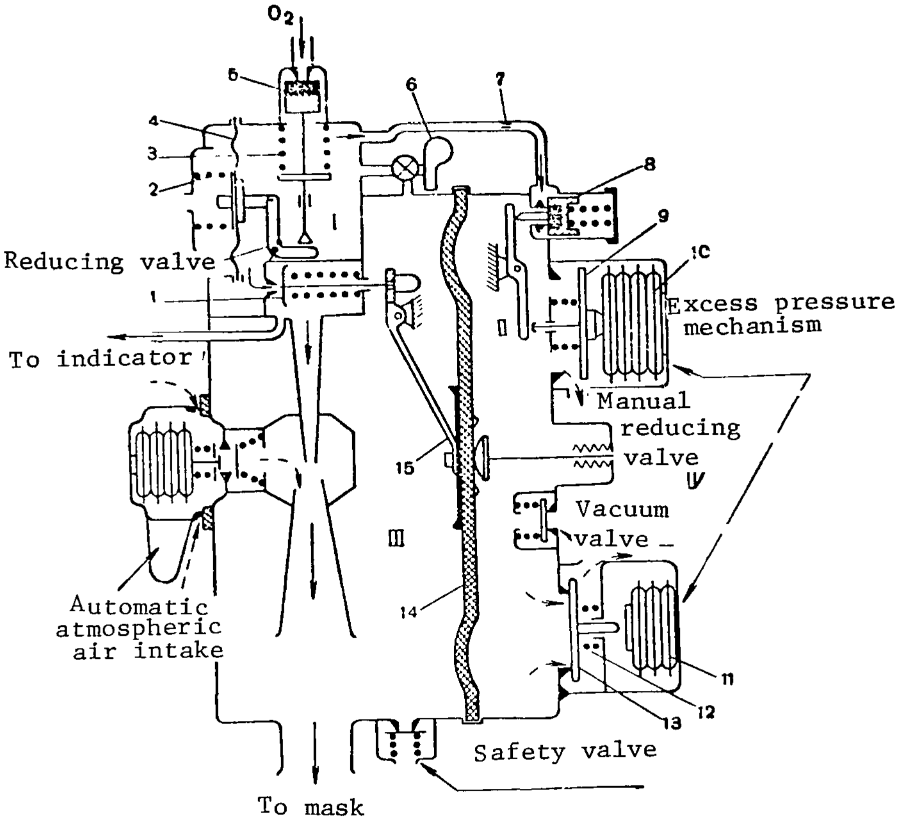

Figure 30. Diagram of oxygen device with excess pressure:

I, II, III - chambers; 1 - pulmonary automatic valve; 2 - main reducing valve spring; 3 - auxiliary spring; 4, 14 - membranes of reducing valve; 5 - intake valve; 6 - emergency oxygen supply valve; 7 - nozzle; 8, 9, 13 - valves; 10, 11 - aneroid chambers; 12 - spring; 15 - handle.

Oxygen devices with excess pressure represent improved pulmonary automatic devices. In flight in a pressurized cabin (at pressures of 0.3-0.4 atm), they work as pulmonary automatic devices and supply the organism with sufficient oxygen at any altitude. If the cabin is depressurized at altitudes above 12,000 m, the devices automatically change over to continuous feed of pure oxygen under excess pressure and maintain sufficiently high partial pressure of oxygen in the alveolar air. In the first case, with a pulmonary ventilation of 15 liters/min, the flow of oxygen changes from 2 liters/min at 5,000 m to 8-10 liters/min at 12,000 m, while in the second case at altitudes of 12,000-15,000 m oxygen is consumed at the rate of 15-20 liters/min.

As we have already pointed out (see Chapter IV), at the present time oxygen devices exist with excess pressure modes of 115, 130 and 145 mm Hg.

Oxygen devices with a pressure mode of 115 mm Hg are used at altitudes up to 15,000 m, and develop an excess pressure in the lungs up to 25 mm Hg, while oxygen devices with a regime of 130 mm Hg can maintain excess pressure in the lungs up to 75 mm Hg at altitudes up to 18,000 m, and devices with a pressure mode of 145 mm Hg can provide excess pressure in the lungs up to 145 mm Hg at altitudes as great above 18,000 meters.

Hence, the oxygen devices intended for breathing oxygen under pressure operate up to 12,000 m as pulmonary automatic devices. The percentile content of oxygen in the inspired gas mixture increases automatically when the aircraft climbs to 10,000 m or less and its partial pressure in the lungs is kept /154
approximately the same as when breathing atmospheric air under terrestrial conditions. At altitudes of 11,000-12,000 m, regardless of the influx of pure oxygen, its partial pressure in the alveolar air decreases somewhat. However, the pilot continues to feel completely comfortable.

In the 115 mm Hg breathing mode, oxygen devices KP-24M and KP-28M operate. The latter, at an altitude of 15,000 m, produces an excess pressure in the lungs up to 25 mm Hg, so that the partial pressure of oxygen in the alveolar air is kept at 45-60 mm Hg and the saturation of the blood with oxygen reaches 75-85%. If the excess pressure in the lungs does not exceed 25 mm Hg, healthy persons undergoing training while breathing under pressure will not show any significant changes in physiological functions.

With a further increase in the excess pressure of oxygen in the lungs, circulatory disturbances and respiration impairment may develop. To prevent adverse consequences due to breathing under pressure at altitudes above 15,000 m, these oxygen devices are used in conjunction with a special pressurizec suit.

Flights at altitudes above 12,000 m using devices intended for breathing oxygen under pressure may be performed by pilots who have carefully studied the device, its principle of operation and the rules for using these devices, and have learned how to breathe under excess pressure.

System of Stationary Oxygen Device KP-24M

The system of the KP-24M device is intended for supplying the flight crew with oxygen in a pressurized cabin at altitudes up to 14,000 m and in a depressurized cabin at altitudes up to 12,000 m for the duration of an entire flight. In the event of cabin decompression at altitudes from 12,000 to 14,000 m, of staying at these altitudes is limited to 5-25 minutes.

The system of the KP-24M device consists of the following:

— oxygen device KP-24M;
— oxygen device KM-32 (KM-30M);
— reducing valve KP-24;
— excess pressure regulating valve RD-24; /155
— oxygen indicator IK-18;
— excess pressure manometer M-1000;
— oxygen hose KSh-24;
— onboard oxygen supply accessories KAB-14;
— parachute oxygen device KP-23;
— portable oxygen supply (KAP).

Oxygen device KP-24M (Figure 31) operates in the pulmonary-automatic mode, and is intended for breathing oxygen under pressure. The oxygen pressure is regulated automatically with altitude.

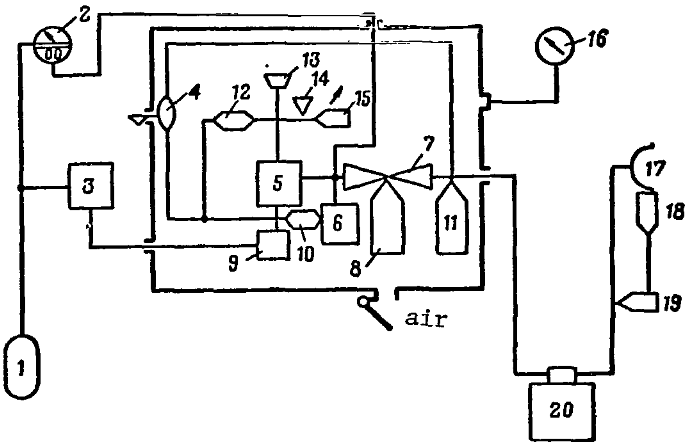

Figure 31. Diagram of KP-24M oxygen device:

1 - oxygen tank (150 kgf/cm^2); 2 - IK-18 oxygen indicator; 3 - reducing valve (12-15 kgf/cm^2); 4 - safety valve; 5 - (main) pulmonary automatic device; 6 - auxiliary pulmonary automatic device (head mechanism); 7 - ejector; 8 - main automatic air intake; 9 - reducing valve; 10 - switching mechanism; 11 - automatic device for auxiliary airintake; 12 - pressurization mechanism; 13 - manual regulator for excess pressure; 14 - vacuum valve; 15 - excess pressure regulator; 16 - M-1000 manometer; 17 - KM-32 oxygen mask; 18 - compensating valve for exspiration (safety valve); 19 - RD-24 excess pressure regulating valve; 20 - KP-23 oxygen device.

The device has three characteristic operation modes.

First Mode. At altitudes up to 2,000 m, the need of the organism for oxygen at low and medium pulmonary ventilation is satisfied only by the oxygen in the air, supplied to the device through an automatic device providing additional inleakage. This allows a more economic consumption of oxygen. The pulmonary automatic device supplies oxygen only on deep inspiration, i.e., with high pulmonary ventilation. When it is necessary to switch over to breathing pure oxygen, the automatic air intake system cuts out manually. From 2,000-5,000-8,000 m, oxygen is supplied by the main pulmonary automatic device. /156

Second Mode. At altitudes of 5,000-8,000 m, the mechanism for low excess pressure of oxygen is activated (head mechanism). If the mask is sealed tightly, a slight excess pressure develops in the breathing system (30-40 mm water column) and the device operates as a pulmonary automatic device. If the mask is applied in such a way that it is not airtight, oxygen constantly leaks out from under it. This means that consumption can rise to 20 liters/min.

With low and average pulmonary ventilation, the oxygen which enters the device through the head mechanism is completely adequate for respiration, so that the main pulmonary automatic device does not operate. With high pulmonary ventilation, in addition to the head mechanism, the main pulmonary automatic device commences operation, making up for the shortage of oxygen.

Third Mode. At altitudes above 11,000 m, the excess oxygen pressure beneath the mask increases with altitude, ensuring that the required partial pressure of oxygen is maintained in the lungs.

With impeded respiration or poor condition (of the user), the emergency valve for oxygen feed is opened manually. In this case, as when using the parachute oxygen device KP-23 or the portable supply KAP, excess pressure in the mask is produced by continuous feed of oxygen and regulated according to altitude by an RD-24 regulator. In case of emergency feed, oxygen is consumed at the rate of 15-23 liters/min.

When the excess pressure in the space inside the device exceeds 800 mm water column, a safety valve opens and the excess oxygen is discharged into the atmosphere.

To create the excess pressure to test the tightness of the mask on the ground, a manual regulator is employed. It is located on the lid of the KP-24M device.

The percentile content of oxygen in the gas mixture reaching the mask /157
from the KP-24M device is shown in Table 17.

The resistance of the device to inspiration under various conditions of operation does not exceed 50-65 mm water column.

Additional oxygen feed to develop an excess pressure begins at 11,000-13,000 m and does not exceed 3 liters/min.

TABLE 17.

Pulmonary ventilation, liters/min	Altitude, m				
	2000	4000	6000	8000	10 000
7.5	27—45	35—55	49—70	68—90	95—100
30	27—55	35—75	49—82	68—100	95—100.

The excess pressure in the device produced by a manual regulator at an oxygen consumption rate of 30 liters/min will reach 400 mm water column.

The values of the excess pressure in the mask (mm water column), developed by the KP-24M device with pulmonary ventilation at the rate of 15 liters/min and oxygen delivered to the device at a pressure of 8 kg/cm^2, are listed in Table 18.

TABLE 18

Phase of respiration	Altitude, m			Temperature of ambient medium, °C
	11,000	13,000	14,000	
Pause Inspiration	40 –	160 40	280 135	+20
Pause Inspiration	– –	– –	330 85	+50

Note: For the values of the excess pressure in the mask, the upper limits are given for the pauses and the lower limits for the inspirations.

Oxygen mask KM-32 (Figure 32). This is a sealed unit which operates under excess pressure, intended for protecting the respiratory organs against the surrounding atmosphere when supplying the pilot with oxygen from an on-board or parachute oxygen device at altitudes up to 18,000 m. The mask is /158 used in conjunction with an interphone headset ShL-60 (ShZ-60). The back part of the interphone headset has a pocket for the tightness compensator.

Figure 32. KM-32 oxygen mask.

A DEMSh-1A microphone is used to carry on radio communications; it is mounted in the body of the mask, or else throat microphones are used.

Under ground conditions, with a constant feed of air at 50 or 90 liters/min, the resistance of the mask to inspiration does not exceed 15 and 35 mm water column, while the resistance to expiration without excess pressure is 35 and 60 mm water column, with an excess pressure of 75 mm Hg (65 and 80 mm water column).

At an altitude of 13,000 m, with a constant flow of air at 15 liters/min at an excess pressure of 22 mm Hg, the resistance of the mask to expiration is equal to 17-30 mm water column, while at an excess pressure of 75 mm Hg it is 27-42 mm water column.

The KM-32 mask, a piece of equipment designed for individual use, is fitted beforehand and fastened tightly to the face and interphone headset of each crew member independently. The masks are made in 5 sizes: the first is smallest and the fifth is largest. The interphone headset is selected to fit the size of the head.

The M-1000 manometer is intended for checking the excess oxygen pressure in the device, while the IK-18 indicator monitors the operation of the pulmonary-automatic device.

Regulator RD-24 is used for automatic regulation of excess pressure beneath the mask and in the tightness compensator (tightening device), depending on the flight altitude at which the parachute oxygen device is to be /159 used, and the portable oxygen supply, or when turning on the emergency oxygen feed for the SP-24M device.

The portable oxygen supply (KAP) is intended to supply oxygen to the crew members when they are moving about the aircraft. The KAP supply system includes the following: a flexible elastic hose, 2.5 m long, with a connector and return valve; a hose connector 0.2 m long, for connecting the elastic hose to the mask; a plug-stopper with a vacuum valve and chain; a tee connector and bag for storing the KAP assembly aboard the aircraft. When switching the oxygen supply from the stationary device to the KAP supply, oxygen is supplied continuously.

System for Stationary Oxygen Device KP-28M

The system of the KP-28M device supplies oxygen to the pilot during flight in a decompressed cabin at altitudes up to 12,000 m, and in a pressurized cabin up to altitudes of 15,000 m for the duration of the entire flight.

In the event of cabin decompression at altitudes from 12,000 to 15,000 m, the length of time the cabin remains habitable is limited to 5-10 minutes.

The system of the KP-28M device consists of the following:

— oxygen device KP-28M;
— oxygen mask KM-32;
— reducing valve KP-28;
— excess pressure regulator RD-28;
— oxygen indicator IK-18M;
— oxygen hose KSh-10;
— onboard oxygen supply KAB-14;
— parachute oxygen device KP-23.

Oxygen device KP-28M (Figure 33) is a pulmonary-automatic device intended for breathing oxygen in a mask under excess pressure. At altitudes

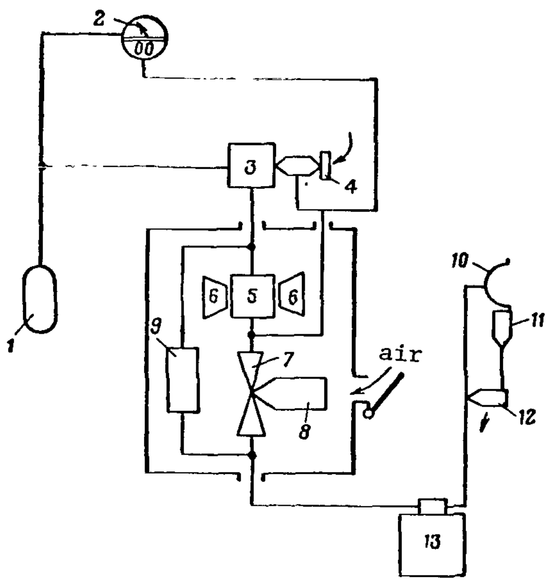

Figure 33. Diagram of KP-28M oxygen device:

1 - oxygen tank (150 kgf/cm^2); 2 - IK-18 oxygen indicator; 3 - KR-28 reducing valve; 4 - emergency valve; 5 - pulmonary automatic device; 6 - head mechanism; 7 - ejector; 8 - automatic air intake; 9 - continuous feed unit; 10 - KM-32 oxygen mask; 11 - compensating exhaust valve; 12 - RD-28 excess pressure reducing valve; 13 - KP-23 oxygen device.

up to 11,000 to 13,000 m, it operates in a mode involving periodic oxygen feed, i.e., like a device of the "pulmonary-automatic" type with excess pressure not exceeding 40 mm water column. Beginning at altitudes /160 of 11,000-13,000 m, the device operates in the mode of continuous oxygen feed, developing excess oxygen pressure beneath the mask corresponding to the flight altitude (Table 19).

The excess pressure is regulated automatically with altitude by pressure regulator RD-28. /161

In the case of pulmonary ventilation at a rate of 7.5 liters/min, oxygen is contained in the following amounts in the gas mixture which reaches the mask: at 4,000 m, 35-55%; 7,500 m, 55-92%; 8,500 m, 90%; 10,000 m and up, 100%.

When using the KP-28M device at altitudes up to 11,000-13,000 m, oxygen is consumed at an average rate of 5.5 liters/min, while at greater altitudes it is used at the rate of 15-20 liters/min.

The partial pressure of oxygen in the inspired air developed by the device at an altitude of 10,000 m reaches 150 mm Hg, 80 mm Hg at 13,000 m, 72 mm Hg at 14,000 m and 68 mm Hg at 15,000 meters.

TABLE 19.

Flight altitude, m	Excess pressure under mask, mm water column	Flight altitude, m	Excess pressure, mm water column	
			on inspiration	on exspiration
4000 8000 10 000	0 40 40	13 000 14 000 15 000	65 135 270	190 280 360

/160

The KR-28 reducing valve reduces the oxygen pressure coming from the tanks at a pressure of 150-30 atm to 8 atm; the RD-28 regulator automatically regulates the excess pressure in the mask at altitudes above 11,000 m when feeding from onboard and parachute oxygen devices; the IK-18M indicator makes it possible to monitor the operation of the KP-28M device.

High Altitude Equipment

Experiments and flight experience at great heights have shown that breathing oxygen under excess pressure without developing a compensatory external counterpressure on the surface of the body is only effective at altitudes up to 15,000 m. At this altitude, the maximum excess pressure in the lungs must be no more than 25 mm Hg, or the partial pressure of oxygen in the alveolar air — 45-60 mm Hg. Under these conditions, although the blood will not be normally saturated with oxygen, the working ability of the pilot will be kept completely satisfactory for a certain period of time.

At altitudes above 15,000 m, with an excess oxygen pressure in the lungs of 25 mm Hg, pronounced oxygen starvation unavoidably develops.

However, if this pressure is increased, pronounced disruptions of circulation and respiration will develop.

In order to avoid these adverse consequences and to make respiration effective under excess pressure, it is necessary to develop a compensatory external pressure (counterpressure) on the surface of the body. This is accomplished by using a compensating suit which covers the entire trunk, as /162 well as the lower and upper extremities. The compensating suit pressurized), suit), in conjunction with the oxygen mask, makes it possible to raise the excess pressure in the lungs to 75 mm Hg, to increase the total pressure in the lungs (with consideration of the pressure of the surrounding atmosphere) to 130 mm Hg (mode "130") and to make it possible for the pilot to stay at an altitude of 18,000 m for 10 minutes in the event that his aircraft cabin depressurizes.

When breathing under excess pressure of more than 75 mm Hg in the mask and pressurized suit, an individual displays stagnation phenomena in the area of the head and neck, i.e., in those areas where there is no compensatory pressure. These phenomena are accompanied by a sharp increase in the blood pressure in the veins and a distention of their walls, a sensation of pain in the area of the eyes, ears, back of the head and neck, flow of tears, and squinting.

Getting rid of these phenomena and raising the excess pressure of oxygen in the lungs still further can only be accomplished by developing external pressure in the area of the head and neck, as well as on the surfaces of the feet and wrists. The external pressure in the area of the head and neck can only be pneumatic. Such pressure may be developed if we replace the oxygen mask with a pressurized helmet. The external pressure on the wrists and feet is developed by special compensatory gloves and socks.

The use of a pressurized suit with a pressurized helmet, as well as compensatory socks and gloves, makes it possible to increase the excess oxygen pressure in the lungs at high altitudes to 145 mm Hg ("mode 145"). This means that the partial pressure of oxygen in the alveolar air at all altitudes (up to altitudes of almost a complete vacuum) will be equal to the partial pressure of oxygen in the alveolar air at an altitude of 12,000 m when breathing pure oxygen without excess pressure. Nevertheless, the time an individual can remain at altitudes above 12,000 m when breathing under excess pressure at 145 mm Hg is limited to 10-15 min. This is explained by the fact that a modern pressurized suit still is not able to distribute the external pressure uniformly over the surface of the body, which would completely equalize the excess intrapulmonary pressure. As a result, circulation and respiration are disrupted to some extent, and, consequently, the period of time that the individual can stay at this altitude is shortened.

To provide a flight crew with the required conditions for vital activity during flights at altitudes above 15,000 m, high-altitude equipment in the form of oxygen-supply systems is used.

Usually, the oxygen-supply system (KKO), operating at pressure modes of 130 and 145 mm Hg, consists of the following:

— a high-altitude compensatory pressure suit (VKK) with compensatory socks and gloves (for "mode 145");
— an oxygen mask or pressurized helmet;
— onboard oxygen device;
— parachute oxygen device;
— regulator for pressure ratio;
— oxygen reducing valve;
— monitoring devices;
— system of onboard supplies;
— oxygen tanks;
— remote control.

The high-altitude compensatory pressure suit consists of overalls, tightening and antioverload devices. The overalls open in front and fasten with "lightning" type fasteners. The same fasteners, but shorter, are sewn into

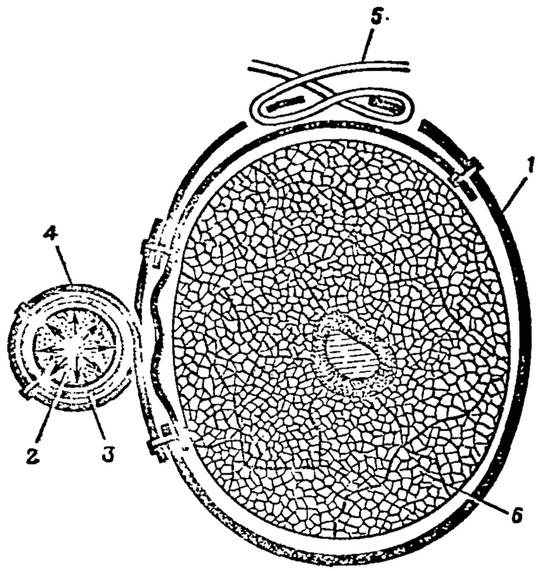

Figure 34. Diagram of compressing action of suit with tightening device:

1 - suit cover; 2 - chamber; 3 - sheath of chamber; 4 - straps of tightening device; 5 - lacing; 6 - chest.

the trousers and gloves. This makes it easier to put on and take off the suit. The overalls are fitted with a system of drawstrings which make it possible to perform individual adjustment.

The tightening device (Figure 34) consists of a chamber, cover and straps. The chamber of the tightening device, protected by a cloth cover, forms the pneumatic system. It is connected to the pressure regulator of the suit. The chamber is located outside the covering of the overalls and is secured in loops formed by straps. The ends of the straps are fastened to the covering of the suit. When there is no pressure in the chamber, the suit fits loosely on the body. When the cabin is decompressed, the chamber of the tightening device automatically fills with oxygen and increases in diameter, tightening the straps, which, in turn, pull on the covering of the suit, creating pressure on the surface of the body.

The antigravity device is mounted into the overalls of the pressurized and forms a whole with it. /164

The effectiveness of the high altitude compensatory pressure suit largely depends on the care with which it is fitted.

The onboard oxygen device supplies a mixture of gas or pure oxygen to the mask or the pressurized helmet. The intensity of the feed is regulated automatically depending on the flight altitude. In the event of cabin

Figure 35. GSh-4MS pressurized helmet.

decompression, the device automatically activates the compensatory suit and develops the necessary excess pressure beneath the mask.

The parachute oxygen device, as we have already said above, supplies the pilot with oxygen and activates compensatory pressure suit if the aircraft is abandoned at high altitudes. The device may be switched on by the pilot in the event the onboard oxygen device fails. /165

The oxygen mask is of the pressurized type; it isolates the respiratory organs from atmospheric air when breathing oxygen under excess pressure, supplied from the onboard or parachute oxygen device when flying at altitudes up to 18,000 m.

The pressurized helmet (Figure 35) carries out all the functions of an oxygen mask; in addition, the pressurized helmet develops pneumatic pressure in the area of the head and neck, balancing the excess intrapulmonary pressure. When leaving the aircraft, it protects the face and head against the blast of /166 air that strikes them.

The pressurized helmet consists of a helmet, face frame with subframes, face plate, lightweight interphone headset and tightening system. The pressurized helmet must provide good visibility, be reliable and convenient to use, have low weight and not limit the movement of the head.

Flights at altitudes above 18,000 m are carried out only with the use of a pressurized helmet.

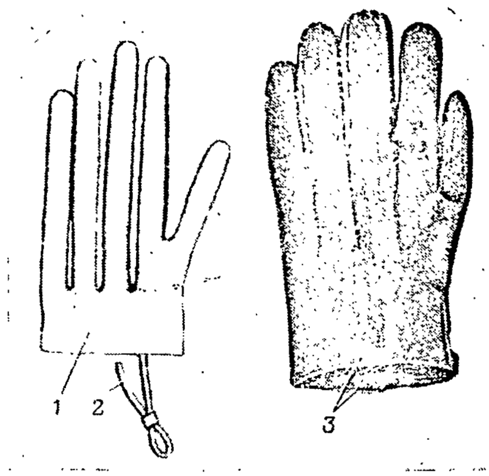

Figure 36. Compensatory gloves:

1 - rubber chamber; 2 - tube to fill rubber chamber; 3 - leather glove.

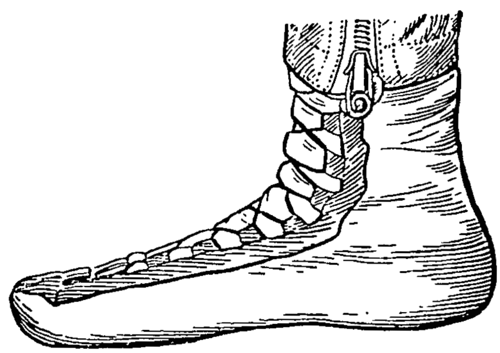

Figure 37. Compensatory socks.

The pressure ratio regulator regulates and maintains the necessary ratio of excess pressure in the chambers of the compensatory pressure suit tightening device and in the mask or pressurized helmet.

Compensatory gloves (Figure 36) are intended to create external pressure on the wrists. The gloves are made of leather or special cloth. The backs have two walls, between which a rubber compartment is located, filled with air. /167
At high altitudes (above 18,000 m), the air in the compartment expands and the gloves tighten on the wrists.

Compensatory socks (Figure 37) develop external pressure in the area of the feet. The socks are sewn from cotton cloth and have special laces to fit them tightly to the foot.

* * *

The preceding is a theoretical description of the purposes, devices and operation of the basic parts of the system which also applies to the majority of existing KKO (oxygen supply systems). Therefore, in the following, when describing specific types of high-altitude equipment, we will only give the individual features of their design and operation.

At the present time, the KKO-1M and KKO-3 oxygen equipment systems are primarily used. There is also high-altitude equipment that uses combined systems for compensation.

Flights using high-altitude equipment may be carried out by pilots who are familiar with the apparatus and rules for its utilization, and have learned to breathe under excess pressure.

The KKO-1M System

The KKO-1M oxygen supply system is designed for individual use; it operates in a pressure mode of 130 mm Hg; in the mask and chambers of the suit tightening device, excess pressure develops automatically. The excess pressure in the mask may reach 75 mm Hg. /168

The system supplies oxygen to the crew members (in a depressurized cabin at altitudes up to 12,000 m and in a pressurized cabin at altitudes up to 18,000) all during the flight:

— in the event of cabin decompression at altitudes of 12,000-18,000 m, for 5-10 min.;

— when leaving the aircraft at altitudes up to 18,000 m; in this case, oxygen is supplied by the KP-27M parachute device.

The KKO-1M system includes the following:

— altitude pressurized suit BKK-3M;

— onboard oxygen device KP-34;

— pressure ratio regulator RSD-1M;

— oxygen mask KM-32 (KM-30M);

— parachute oxygen device KP-27M;

— oxygen reducing valve KP-26;

— oxygen indicator IK-18;

— M-2000 manometer;

— onboard supply system KAB-16;

— oxygen tanks;

— remote control.

Operation of the KKO-1M system. The KKO-1M system operates in a depressurized cabin at altitudes up to 12,000 m and in a pressurized cabin at altitudes of 12,000-18,000 m like an ordinary automatic pulmonary device. The partial pressure of oxygen in the mask is maintained by increasing its percentile content in the inspired mixture. At an "altitude" in the cabin of up to 10,000 m, a mixture of oxygen with air is supplied, while pure oxygen is fed at "altitudes" greater than 10,000 meters.

In the event of cabin depressurization at altitudes of 12,000-18,000 m, the continuous oxygen supply is switched on automatically, and an excess pressure beneath the mask is developed in the course of 2-3 sec while the high-altitude flying suit is activated. The latter creates a counterpressure on the surface of the body which is approximately equal to the excess pressure in the respiratory system. In the chambers of the tightening mechanism, the /169 pressure (and therefore the tightening of the pilot's body) develops 1-2 sec earlier than the excess pressure in the respiratory system. The excess pressure in the mask (in the respiratory system) and in the chambers of the tightening device is regulated automatically as a function of altitude.

At altitudes up to 12,000 m, the KKO-1M system may be used without a pressurized suit.

Oxygen device KP-34 operates when oxygen is fed to it at a pressure of 30 to 6 atm (or 150 to 30 atm, if oxygen is supplied through reducing valve

KR-26). When the device is operating in the continuous-feed mode, oxygen is consumed at the rate of 14-20 liters/min.

The resistance of the device to inspiration under ground conditions with the automatic air pump shut off and oxygen supplied at 8 atm to the device does not exceed the values given in Table 20.

TABLE 20.

Pulmonary ventilation, liters/min	Temperature of ambient medium, °C	Resistance to inspiration, mm water column
15	+20, +50	50
15	—50	65
30	+20	90

System KKO-3

The KKO-3 oxygen equipment system (Figure 38) is designed for individual use; it operates in a pressure mode of 145 mm Hg. This mode is made possible by a pressurized helmet and improved compensation of excess pressure in the lungs with the aid of improved high-altitude compensating suits.

The system provides oxygen to the crew members:

— in a depressurized cabin at altitudes up to 12,000 m and in a pressurized cabin at altitudes above 18,000 m, during the entire duration of the flight;

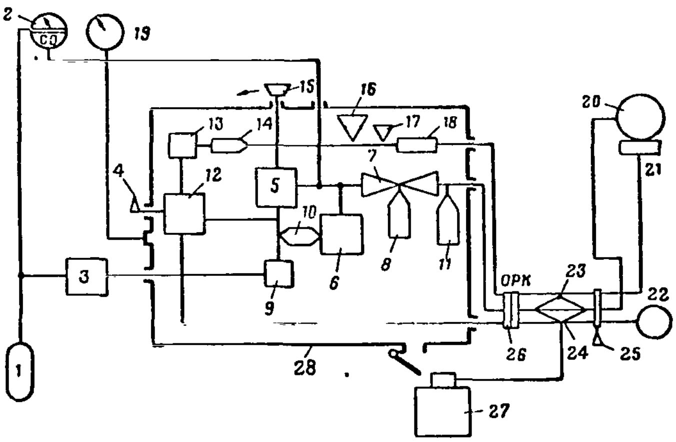

Figure 38. Block diagram of KKO-3 oxygen equipment:

1 - oxygen tank (150 kgf/cm^2); 2 - IK-18 oxygen indicator; 3 - type KR-26A reducing valve; 4 - emergency valve; 5 - main automatic pulmonary device; 6 - auxiliary pulmonary device; 7 - ejector; 8 - main automatic air intake; 9 - reducing valve of the device; 10 - mechanism for cutting in additional pulmonary automatic device; 11 - auxiliary automatic air intake; 12 - continuous feed section; 13 - time-delay relay; 14 - blocking valve; 15 - manual pressure regulator; 16 - aneroid safety valve; 17 - vacuum valve; 18 - valve box; 19 - M-2000 manometer; 20 - GSh-4MS (KM-32) pressurized helmet; 21 - compensating exhaust valve; 22 - high-altitude compensating suit (VKK-4, VKK-4P, VKK-6M); 23 - excess pressure regulator; 24 - pressure-ratio regulator; 25 - emergency hose cut-off; 26 - common communication hookup; 27 - KP-27M oxygen device; 28 - KP-34 oxygen device.

— onboard-supply system KAB-16;

— oxygen tanks.

— in the event of cabin decompression at altitudes above 12,000 m, for 5-10 min;

— when leaving the aircraft at altitudes above 18,000 m; in this case, the oxygen supply comes from the KP-27M parachute device.

The KKO-3 system includes the following:

— high altitude flying suit VKK-6M (VKK-4, VKK-4P);

— oxygen device KP-34;

— pressurized helmet (GSh-4MS (oxygen mask KM-32);

— parachute oxygen device KP-27M;

— pressure ratio regulator RSD-3M;

— compensating socks and gloves;

— remote control;

— oxygen reducing valve KR-26; /171

— oxygen indicator IK-18;

— manometer M-2000;

The high-altitude compensating suit VKK-6M (Figure 39) consists of overalls with tightening laces and antigravity devices.

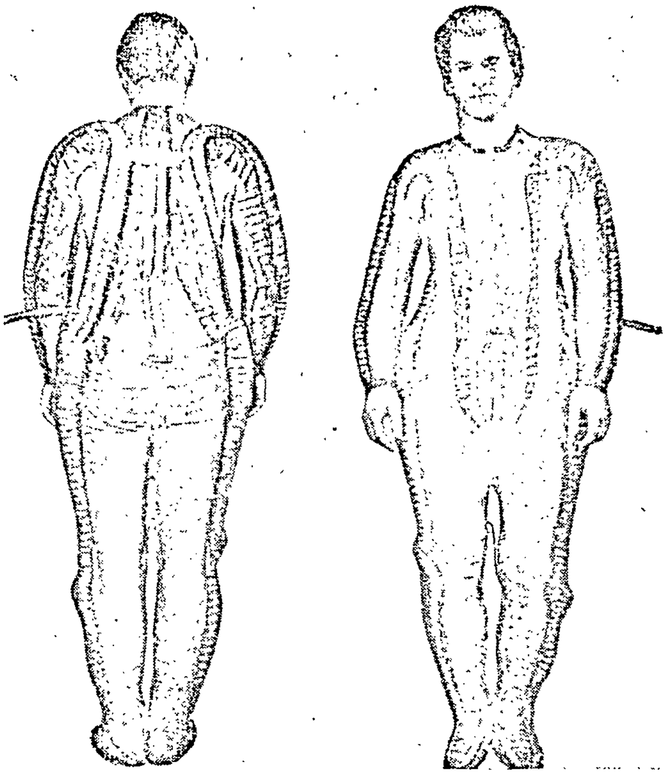

Figure 39. VKK-6M high-altitude compensatory pressure suit.

The cut of the suit is designed for a "seated" position, which allows the necessary mobility and comfort of the pilot's position in the ejection seat. /172

In a pressurized cabin at altitudes above 12,000 m or in a depressurized cabin at altitudes up to 12,000 m, the suit does not operate. It is switched on automatically at altitudes above 12,000 m if the cabin is depressurized and oxygen begins to flow into the tightening device chamber.

The oxygen pressure in the chambers is regulated automatically by the RSD-3M regulator; as the pressure in the cabin decreases, the pressure in the pressurized helmet and the chambers increases, so that the tightness of the suit on the body becomes greater. However, the resultant pressure on the pilot's body (total of atmospheric and mechanical compensating pressures at each altitude) remains constant regardless of altitude, and is equal to the pressure at an altitude of 12,000 m.

During flight, the chambers of the tightening device are filled from the onboard oxygen system, while during descent by parachute, they are supplied by the parachute oxygen system.

The antigravity system (PPU) consists of one abdominal and two leg rubber chambers. They are all connected together. The chambers are enclosed in capron jackets. The leg chambers are mounted in the tightening device of the suit in the portion from the waist to the trouser cuffs, while the abdominal chamber is attached to buttons inside the overalls in the area of the abdominal wall.

The pressure in the chambers of the antigravity device is produced with the aid of an automatic device (AD-6E) and regulated depending on the value of the overload, changing within limits from 1.75 to 10. The automatic device is switched on when the overload reaches a certain value, and operates independently of the tightening device.

The abdominal compensator is a rubber chamber located in a capron jacket. The air in it expands under low pressure and creates a mechanical pressure in the area of the stomach.

High-Altitude Equipment with a Combined Compensation System

Equipment with a combined compensation system (Figure 40) makes it possible for the pilot to retain normal working ability when he is in a depressurized cabin during flight at a high altitude for 1-1/2 to 2 hours.

The equipment includes: /173

— high-altitude compensatory pressure suit with combined compensation system;

— pressurized helmet;

— compensating gloves and socks;

— oxygen device;

— parachute oxygen device.

The high-altitude suit with combined compensation system differs from those described above in that the balancing counterpressure on the trunk is created by a special respiratory-compensating chamber, while on the extremities it is produced by the chambers of the tightening mechanism. The respiratory-

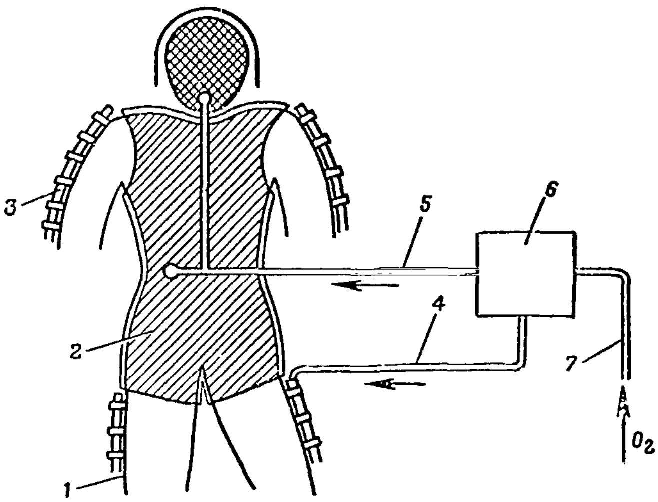

Figure 40. Schematic diagram of combined compensating suit:

1 - suit material; 2 - breathing-compensating chamber; 3 - tightening device; 4 - hose to feed oxygen to chamber of tightening device; 5 - hose to feed oxygen to breathing-compensating chamber and pressurized helmet; 6 - oxygen device; 7 - hose to feed oxygen from tank.

compensating chamber resembles a bathing suit, which fits closely to the trunk. This means that a more uniform counterpressure is developed. /174 The necessary pressure in it is created automatically with the aid of an oxygen device, depending on the flight altitude.

The oxygen device in this system is a pulmonary-automatic operating type. However, it does not have devices for drawing in atmospheric air, so that pure oxygen is supplied to the respiratory system at all altitudes.

During flight at altitudes up to 12,500 m in a pressurized or depressurized cabin, the pressurized helmet and respiratory-compensating chamber maintain an excess pressure in the neighborhood of 100 mm water column.

In the event of chamber decompression at altitudes above 12,500 m, the pressurized helmet and breathing-compensating chamber maintain an absolute pressure of about 145 mm Hg ("145 mode"). At 12,500 m, the chambers of the tightening device also begin to fill with oxygen. The desired pressure is maintained in them by the pressure ratio regulator.

The oxygen system and oxygen tank for the parachute device are located in a special pack worn by the pilot.

Flying Suits

A flying suit is a pressurized suit designed as individual high-altitude equipment for a pilot. It produces favorable physiological-hygienic conditions (pressure, temperature, humidity and gas mixture composition) for the vital activity of the pilot in high-altitude flights. Therefore, the suit has considerable advantages over the oxygen-supply systems discussed above. This makes it possible to carry out long flights at practically any altitude with the aircraft cabin depressurized, provides reliable protection against the influence of low barometric pressure, as well as high and low temperature. Pressure changes may easily be withstood in the flying suit; this softens the impact of the air blast which strikes the pilot upon ejection and promotes flotation in the event of landing on water.

The high-altitude flying suit consists of the following:

— pressurized overalls;
— pressure regulator;
— safety valve; /175
— helmet;
— protective outer clothing;
— heat-protection suit;
— ventilating suit;
— emergency and rescue equipment.

The pressurized overalls with pressurized covering are made of strong cloth which is impermeable to gas, while the removable gloves and boots are made of special material. The pilot dons the suit on the ground.

To provide the pilot with sufficient mobility in the area of the joints, the suit has special articulations.

The helmet is connected to the overalls in an airtight fashion. The helmet may be removable or nonremovable, turning together with the head, or fixed but providing the possibility of freely moving the head inside it. The helmet has a tilting face plate, a light filter, and a pressure drop valve. The face plate must provide the pilot with a good view.

Necessary living conditions in the suit are maintained with the aid of the units that make up the system.

During flight in a pressurized cabin, the suit is in an inoperative condition and is continuously ventilated with air which comes from the cabin ventilation system. At the airfield, the suit is ventilated with the aid of a ground air-conditioner or a special portable ventilator.

When it is necessary to maintain the partial pressure of oxygen in the suit at the level necessary for breathing, excess pressure is developed relative to the pressure in the surrounding atmosphere.

At all altitudes, the absolute pressure (atmospheric plus excess) is maintained in the suit between 170 to 198 mm Hg, corresponding to an altitude of 10,000-11,000 m.

To prevent the development of decompression problems in the suits, the possibility must be provided for increasing the absolute pressure to 267-308 mm Hg.

Depending on the manner in which the oxygen is provided, suits may be provided with or without masks. In the mask-type suits, oxygen for breathing is supplied to the oxygen mask, while in the maskless type they are supplied /176
to the cavity of the pressurized helmet.

According to the method of operation, suits are categorized into ventilated and regeneration types.

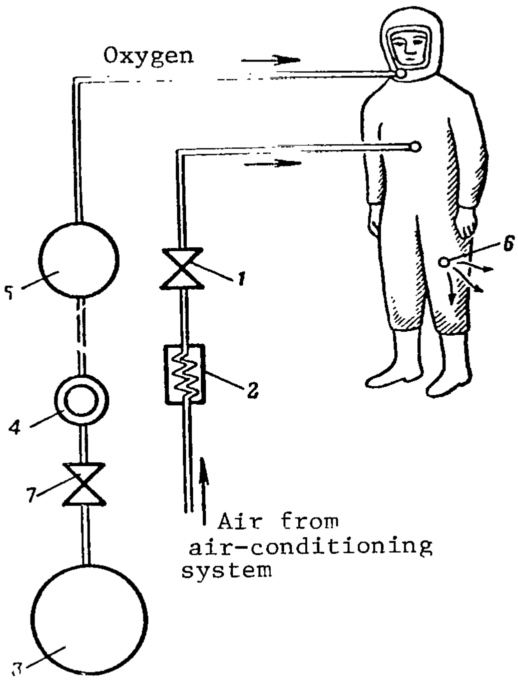

Figure 41. Schematic diagram of supply to ventilated-type flying suit:

1 - regulating valve for air supply; 2 - heat exchanger: 3- oxygen tank; 4 - reducing valve; 5 - oxygen device; 6 - pressure regulator; 7 - instrument valve.

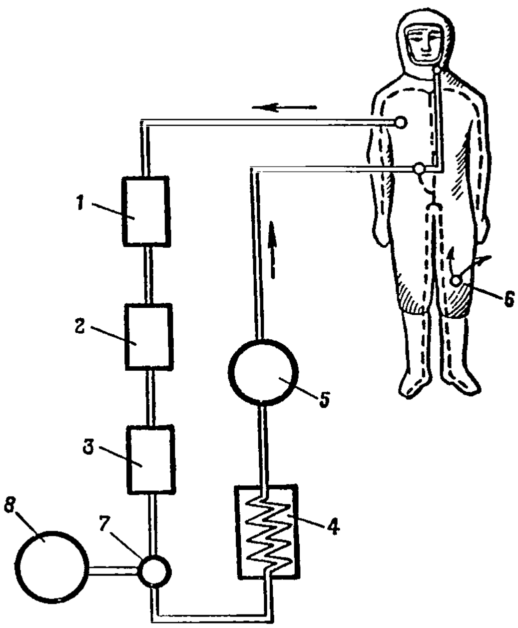

Figure 42. Schematic diagram of supply system for regeneration-type flying suit:

1 - CO_2 absorber; 2 - moisture absorber; 3 - filter; 4 - heat exchanger; 5 - pump; 6 - pressure regulator; 7 - oxygen feed regulator; 8 - oxygen tank.

During flight the ventilation-type suit (Figure 41) is connected by a special hose to the pressurization system for the pressurized cabin. The air for ventilating the suit and maintaining the excess pressure in it comes from the air-conditioning system, while the oxygen for breathing comes from tanks on board. The air which enters for ventilation is vented continuously to the outside through a pressure regulator.

In the event that the cabin pressurization is disrupted above 11,000 to 12,000 m, appropriate excess pressure develops automatically in the suit in the course of 2-3 sec. /177

The oxygen for the pilot comes from a special oxygen device with pulmonary-automatic operation. A device of this kind is included in the system of the suit.

The regeneration-type suit (Figure 42) operates with a closed ventilation cycle and a constant air volume. From the suit, the air passes into the regeneration device. Here carbon dioxide is absorbed as well as moisture; the air is enriched with oxygen and again enters the suit. The excess air which is formed as a result of the continuous supply of oxygen is discharged into the atmosphere through the pressure regulator.

To absorb carbon dioxide, soda lime or lithium hydroxide are usually used, while silica gel (a specially processed form of sodium silicate) is used to absorb moisture. /178

Various odors are removed by an absorber using activated charcoal.

During normal flight in a pressurized cabin, the ventilation of the space beneath the suit and the supply of oxygen to the pilot are accomplished in the same fashion as in the ventilated type of suit. In the event that the cabin pressurization breaks down, the regeneration type suit automatically switches to a closed ventilation mode.

The consumption of oxygen in regeneration type suits is comparatively low and is about 0.5-1 liters/min.

* * *

To provide protection against fire, certain suits are supplied with oxygen only in the space formed by the pressurized helmet, while the space beneath the suit is ventilated with air or nitrogen.

When leaving the aircraft, all types of suits are automatically disconnected from the connecting hose and connected to the parachute oxygen device, which provides the pilot with oxygen until he reaches a safe altitude and maintains the necessary pressure in the suit.

All suits are provided with emergency-rescue equipment. These items are located directly on the suit. They include the following: an inflatable collar, radio transmitter, signalling equipment, food supply, etc. The inflatable collar (capacity of 30-40 liters) fills with carbon dioxide from a special tank when landing on water.

Despite its definite advantages, the high-altitude suit still has not found practical application in aviation. The principal reasons for this are the following:

— the need for constant ventilation of the space beneath the suit all during the time the pilot is in the suit;
— inconvenience of putting it on;
— considerable difficulty of movement for the pilot during flight;
— the large size of the suit.

Oxygen and Its Properties

Oxygen is a transparent colorless gas, which has neither smell nor taste; /179
it exhibits considerable chemical activity.

Oxygen is heavier than air (at a temperature of 0 °C and a pressure of 760 mm Hg, 1 m^3 of gaseous oxygen weighs 1.428 kg, while 1 m^3 of air weighs 1.293 kg). Oxygen is also found in the liquid and solid states as well as in the form of a gas. At ordinary room temperature, oxygen cannot be liquified, regardless of pressure.

It changes to the liquid state at a temperature of -118.8°C and a pressure of 51.35 atm. This temperature and pressure are termed critical.

At normal atmospheric pressure (760 mm Hg) this transition is possible at a temperature of −182.95 °C. Liquid oxygen is a mobile transparent mass which is blue in color. The specific gravity of liquid oxygen is 1.118 g/cm^3, and 1 liter weights 1.146 kg.

When cooled to −218.4 °C at a pressure of 2 mm Hg, liquid oxygen changes to the solid state. Solid oxygen has the appearance of a friable snow-like mass. During the change from the liquid state to the gaseous state at zero temperature and normal atmospheric pressure, one liter of liquid oxygen will form 800 liters of gas.

Oxygen is the most widespread element on our planet. It makes up almost 50% of all the material on Earth. Its content in the air is about 21%. In the free state, it is found only in the atmosphere. Oxygen is widely used in industry, aviation, and so on. Industry produces technical and medical grades of oxygen.

Medical oxygen (All Union State Standard 5583-58) is used in aviation; it contains at least 98.5% oxygen and a maximum of 0.07 g/m^3 of moisture. It may not contain any carbon monoxide, ozone, carbon dioxide, gaseous acids or bases. Medical oxygen may not have any odor.

As we know, the process of combustion takes place very intensively in pure oxygen.

In this connection, it is often stated that breathing pure oxygen promotes more intensive oxidation processes in the cells and tissues of an organism, and this means that they will "burn out" prematurely, and that the breathing of pure oxygen causes harm to the organism in general. /180

However, studies which have been conducted in connection with this problem over the last few decades in the USSR and abroad indicate that, when pure oxygen is breathed under pressure in excess of atmospheric pressure, there is no intensification, but rather a marked inhibition of oxidation processes in the cells and tissues.

An individual can be intoxicated only in the event that he breathes pure oxygen at a pressure of more than 2 atm for several hours. Thus, for example, signs of intoxication in the form of spasms may occur on the average after 3 hours of staying in a chamber filled with pure oxygen at a pressure of 3 atm. When breathing pure oxygen under pressure of 4 atm, intoxication occurs in 40-45 min.

Hence, the higher the oxygen pressure, the faster and more severe the signs of intoxication.

However, when breathing pure oxygen for several hours under pressure equal to normal atmospheric, no negative signs in the condition of the organism are observed.

We know that the flight crew must not breathe oxygen under pressure greater than 1 atmosphere, so there is no basis for being afraid that it will have a toxic effect. This is supported by numerous experiments in barochambers and the extensive experience of flights using oxygen respiration apparatus.

To supply oxygen for flights, medical oxygen is carried as a rule in 40-liter tanks at a pressure of 150 atmospheres. The tanks, with a capacity from 4 to 12 liters, are mounted aboard the aircraft, usually with a working pressure of 150 atm.

The amount of oxygen in the tank is measured in liters at a pressure of 760 mm Hg and a temperature of +15 °C. In order to determine this amount, it is necessary to multiply the capacity of the tank by the pressure of the oxygen in it. For example, in an 8-liter tank with a pressure of 150 atmospheres at +15 °C, there will be 8 X 150 = 1200 liters of oxygen.

We know that, as the temperature of the air drops by 1°C, the oxygen pressure in the tank decreases by 1/273. Accordingly, there is a decrease in the amount of oxygen in it. Let us assume that at a certain flight altitude the temperature is -50°C. This means that in this case the temperature will drop by 65°C relative to +15°C. Consequently, the pressure in our 8-liter tank will decrease by 65/273 from the initial value, i.e., it will be equal to approximately 114.3 atm: /181

$$150 - \frac{150 \cdot 65}{273} \approx 114.3 \text{ atm} .$$

The supply of oxygen decreases to 8 x 114.3 $\approx$ 914 liters.

Due to the high chemical activity of compressed gaseous oxygen when it comes in contact with oil or grease, there is spontaneous combustion of the mixture which is formed, which often has the nature of an explosion. Therefore, in order to maintain safety in places where oxygen is stored and where equipment is used in which it is found under high pressure, it is necessary to exclude the possibility of its coming in contact with oil and readily inflammable materials.

Liquid oxygen is stored in special gasifiers; each gasifier consists of a vessel for the oxygen, an evaporator, and connectors.

It is also necessary to carry out safety measures when working with liquid oxygen. Liquid oxygen may cause deep burns when it touches the skin. If cotton material is soaked in it, a powerful explosion will take place if this material ignites.

When working with liquid (gaseous) oxygen, one must take care so that it does not saturate the clothing and hair as it evaporates, otherwise it may easily catch fire in the presence of an open flame and cause severe burns.

CHAPTER VII

ACCELERATION IN FLIGHT AND ITS EFFECT ON THE HUMAN ORGANISM

During long evolutionary development, man has become accustomed to certain conditions of existence, including a certain rate of movement.

Even 60-70 years ago, the maximum speed at which a human being could travel did not exceed 45-50 k/hr. As science and technology developed, the rate of movement increased; this became especially noticeable with the appearance of internal combustion engines, as well as jet engines. At the present time, it has already exceeded the speed of sound several fold. Rocket motors have made it possible to reach the first (7.8 km/sec) and second (11.2 km/sec) cosmic velocities. This has made it possible to make flights into space.

We know that any movement of man in space unavoidably is accompanied by the action on him of various accelerations, both in terms of magnitude and direction. At modern speeds, the problem of studying the resistance of man to acceleration has become very timely both in the technical and medical spheres. This is particularly important as a problem for aviation and cosmonautics. In this connection, aviation medicine was faced with a problem of studying the influence of acceleration on the organism in depth and from all aspects; it became necessary to develop methods of eliminating or attenuating its effects.

In high-altitude flight, the operating conditions of the pilot, of course, /183 are much more complex and difficult than in low-speed flight. However, speed itself does not have any harmful effect on the human organism. In a closed cabin which provides sufficient protection against the influence of the incident flow of air, a human being can withstand any speed if the direction of motion of the aircraft and the speed itself remain constant.

General Concepts Regarding Acceleration

Velocity is an expression of the relationship of distance to the time during which a body covers this distance. If a moving body covers an equal distance in equal time segments, i.e., if the velocity remains constant with time, movement of this kind can be called uniform. However, if the body covers a different distance at different time segments, its movement is called nonuniform.

In daily life, nonuniform movement is the type most often encountered, in which speed changes both in magnitude and direction, or simultaneously in magnitude and direction. In mechanics, any change in velocity in terms of magnitude or direction in a unit time is called acceleration.

According to the first law of mechanics, any body is at a state of rest or uniform movement in a straight line until some external force alters this state. Consequently, a change in velocity in terms of magnitude or direction, i.e., acceleration, develops under the influence of external forces.

We know from the second law of mechanics that acceleration is directly proportional to the unbalanced force acting on the body and inversely proportional to its mass:

$$a = \frac{F}{m},$$

where F is the force acting on the body, and m is the mass of the body.

Hence, if we know the mass of the body and the acceleration, we could get some idea of the force acting on the body and causing the acceleration. Acceleration is usually expressed in meters per second squared (m/sec^2). In aviation, a unit of acceleration is widely employed which is equal to the normal acceleration of the force of gravity, 9.81 m/sec^2. This value is /184 represented by the letter g. For example, acceleration equal to 50 m/sec^2 may be represented by 5 g, i.e., 50:9.81 approximately equals 5 g. This provides a basis for expressing the acceleration which develops in any form of movement in units of acceleration due to the force of gravity. From acceleration of free fall it follows that the acceleration equal to 9.81 m/sec^2 caused by the force of gravity is equal to the weight of a body. Thus, if the acceleration is equal to 5 g, the force that is produced is 5 times greater than the weight of the body.

It follows from this that, when the speed or direction of movement is changing, it is not acceleration alone that acts on the body, but the external forces causing it. These forces are called inertial, i.e., they confer inertia to the accelerated body. In terms of magnitude, the forces of inertia are equal to the forces causing acceleration but directed in the opposite direction. Persons frequently encounter inertial forces in trains and in different forms of transport. At the beginning of movement, the acceleration and the force causing it are directed forward (in the direction of movement) while the passengers feel the effect of the inertial force pushing them backward. In the event of sudden braking and stopping, the opposite happens: the acceleration and the force causing it are directed backward and inertia pushes the passengers forward.

In aviation medicine and technology, one frequently encounters the concept of "overload". This concept is conditional. An overload is a relative value which indicates how many times the force causing acceleration is greater than the weight of the accelerated body. Overload is measured in units which are multiples of the weight of the body under terrestrial conditions. In a state of rest, a body is subjected to an overload equal to unity. If an external force confers an acceleration of 5 g on a body, the overload will be equal to 5. This means that the weight of the body under these conditions will be increased 5 times relative to the original value.

We assume in aviation medicine that the force acting on the pilot is equal to the acceleration, i.e., F = a. Consequently, when we talk about the influence of acceleration, it is necessary to imply the mechanical force which is acting at a given moment on the human being, and when we are talking about overload we have in mind the ratio of the acting force to the weight of the body.

Depending on the direction of action relative to the body of the indivi- /185 dual, we have the following different types of overloads: longitudinal, transverse and lateral. An overload is termed linear when it acts in the direction from the head to the feet (head to the pelvis) or vice versa, transverse if it acts in the direction from the chest to the back or vice versa, and lateral when it acts from side to side (Figure 43). The effect of overload is opposite in direction to the action of acceleration. For example, if acceleration is acting in the feet-head direction, the overload (inertial forces) will be directed from the head to the feet.

Acceleration with a duration of action up to 1 sec will be conditionally given the name of short-term, while that which lasts more than 1 second will /186 be called long-term.

The nature of the change in the physiological functions of the pilot's body, and his working ability under the influence of acceleration depend on the nature and the magnitude of the acceleration, the duration and direction of its action, the number of times the action is repeated, as well as the physical state and individual characteristics of the pilot's body. The nature of these changes may differ from insignificant unpleasant feelings to extremely serious conditions accompanied by marked disturbances of the activity of the respiratory organs, the cardiovascular, nervous and other systems of the body, even loss of consciousness and traumatic injury.

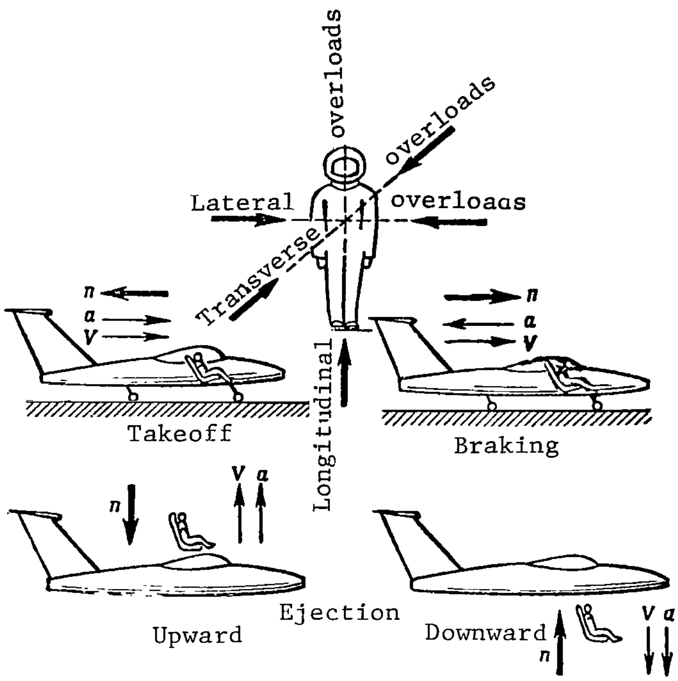

Figure 43. Classification of overloads (a = acceleration; v = velocity; n = = overload).

An individual who is subjected to the action of acceleration feels a sense of heaviness all over his body, difficulty in making movements, and sometimes pains in the area of the chest or stomach. At certain levels of acceleration, disturbance of vision may occur.

We know that the action of the force that delivers additional speed to a given body not only acts at the point of application of this force, but is also propagated through the entire body, causing a relative shift and deformation of its parts. These shifts and deformations increase in severity as the acting force increases, and the cohesion between the parts of this body becomes weaker. Human tissues and organs have various physical properties and degrees of internal cohesion. Consequently, inertial movement and deformation take place to different degrees.

Under the influence of acceleration, it is the soft tissues which undergo maximum shifting and deformation (blood, soft tissues of the face), as well as those internal organs (organs in the abdominal cavity), which have great weight and insufficient fixation. The greatest inertial displacement is seen in the case of the blood, which has the least solid internal connections. This kind of shift is promoted by the high level of elasticity of the vessels. Under the influence of acceleration acting for a long time and directed along the large blood vessels the blood moves easily from one part of the body to another. Therefore, it is disruption of the circulation under the influence of acceleration (overload) which is observed most frequently.

At low levels of acceleration, the deformation of the organs and tissues does not cause a significant disruption of their functions. However, as the acceleration increases, this deformation may cause a sharp disruption of the functions of individual organs and the body as a whole. /187

During flight, an aircraft often changes its rate of movement and direction, so that accelerations develop. Acceleration in flight may develop with a change in velocity but with retention of the direction of movement or, on the other hand, at constant velocity but with a change in the direction of movement, as well as with simultaneous change in velocity and direction of movement.

In aviation practice, one usually finds accelerations of the following four types: linear, radial, angular and Coriolis.

Linear Acceleration and Its Influence on the Human Organism

Linear acceleration develops during a change in speed which is not accompanied by a change in direction of movement. If the speed increases, the acceleration is positive; if it decreases, acceleration is negative. Long-term and short-term accelerations are determined by the length of time they operate, as we have already mentioned.

Linear acceleration may be computed by the following formula:

$$a = \frac{v_t - v_0}{t},$$

where v_t is the final velocity in m/sec, v_0 is the initial velocity in m/sec, and t is the time during which the velocity changes, in seconds.

In aviation practice, linear accelerations are observed during takeoff and landing, during acceleration and braking of the aircraft in flight, during launching from catapults, during the opening of the parachute and landing of a parachutist, when ejecting a pilot out of the aircraft cabin, and also during emergency landings. The duration of action of such accelerations varies from fractions of a second to several seconds.

Linear acceleration may act in the back-chest direction and the chest-back direction, as well as legs-head and head-legs. /188

During takeoff, the pilot is subjected to the action of positive linear acceleration, while during landing this is negative. With a normal posture of the pilot in the cabin on takeoff, acceleration acts in the direction from the back to the chest, and the overload works in the opposite direction from the chest to the back, pressing the pilot against the back of his seat. During a landing run, however, acceleration acts in the chest-back direction and the overload is in the back-chest direction, pulling the pilot away from the back of the seat.

Linear accelerations which develop during takeoff and landing of an aircraft, as well as during change of velocity during flight, have practically no unfavorable effects on the pilot's body. This is explained by the fact that in these instances accelerations usually have a low value (0.4-1 g), and they act for a short space of time in a direction in which they are withstood most easily by the organism. Since man has no large blood vessels which are located perpendicular to the longitudinal axis of his body, the inertial changes in the blood in the transverse direction are insignificant.

However, with a strictly transverse direction of acceleration, the mechanical forces exert pressure on the area of the chest and stomach, making it more difficult to carry out respiratory movements with the chest cavity and the anterior wall of the stomach. Therefore, with a sufficient magnitude and duration of action of this kind of acceleration, both respiratory and circulatory disorders of the lungs may play a leading role in the general picture of the disorders observed in the organism.

The most general reaction of the organism to the reaction of transverse overloads is a speeding up of respiration. According to the data from observations, with an acceleration of 7-10 g, the frequency of respiration and the pulmonary ventilation increase on the average by 1-1/2 to 2 times, while at acceleration of 6-8 g there is a definite difficulty of inspiration due to compression of the rib cage. However, even at an acceleration of 12 g and sufficient fixation of the trunk and head, there will not be any danger of any kind as far as the body is concerned.

As the linear transverse acceleration increases, there is a noticeable disruption of respiration and the development of painful feelings in the area of the chest cavity. The pressure on the chest cavity and the compression of the lungs makes it more difficult to breathe; respiration becomes superficial /189 and more frequent. It has been determined experimentally that even with a linear acceleration of 8 g the vital capacity of the human lungs is reduced significantly in comparison with the original value. In addition, it is possible to have disruption of the circulation in the lesser circulation.

Linear accelerations are greatest when the pilot is ejected from the aircraft cabin, his parachute opens, an aircraft is launched from a catapult, and in crash landings. In these cases, the action of mechanical forces develops in a short period of time and acquires the nature of a shock. Therefore, accelerations of this type have been called "shock accelerations". As a rule, shock acceleration acts for no more than one second (and in many cases tenths or hundredths and even thousandths of a second). The rate of development of shock acceleration may reach hundreds and thousands of g's per second.

The degree of action of a shock acceleration is determined by the magnitude of acceleration, the time of its action, and the rise time. It is obvious that the faster the acceleration and the rise time, the greater the danger of injury. As a result of the action of shock acceleration, various organs and tissues are deformed so that at high accelerations there may be concentrated or generalized trauma.

Effect of Linear Acceleration During Ejection

Ejection is the emergency removal of the pilot from the aircraft cabin together with his seat. After passing over the tail of the aircraft, the pilot falls into a zone which is safe for the parachute to open.

The need for ejection is caused by the fact that, in the event that an emergency situation develops at a flight speed above 500 km/hr, the majority of pilots do not have the physical strength which is required so that they can emerge from the aircraft cabin after overcoming the incident flow of air; the force of this airflow is so great that after emerging the pilot is unavoidably pushed against the tail assembly (Figure 44) and injured.

We know that even at a velocity of 250 km/hr, the pilot must expend considerable effort and time, and must have a certain degree of training. At a speed of 400 km/hr, a pilot with average physical development will still have sufficient energy to be able to overcome the resistance of the velocity head of air without having to resort to the aid of an aircraft ejection device. At a speed of 500 km/hr, it is very difficult and dangerous to heave the aircraft on one's own. At a flight speed of 600 km/hr, it is practically impossible to leave the aircraft without the aid of an ejection system. If we assume that the pilot weighs 70 kg, calculations will show that at a flight speed of 800 km/hr the force of the pressure of the airstream will exceed the weight of the pilot by a factor of 44, at 1000 km/hr by 67 and 1500 km/hr by 155.

Statistical data show that during the World War II, out of 1,178 parachute jumps made from high-speed aircraft by German Luftwaffe pilots who did not have ejection equipment, 158 resulted in serious injury. In the United States Army Air Force, 24% of the pilots who jumped with parachutes from high-speed

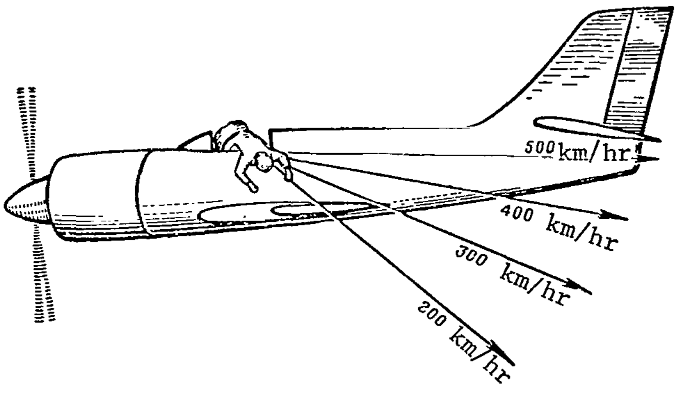

Figure 44. Relative trajectories of movement of pilot on leaving an aircraft at various flight speeds.

aircraft in 1943 received serious injuries due to striking the tail assembly. During the period from 1944 to 1949, out of 850 emergency exits from aircraft of different types, 51% involved the pilots being injured to various degrees, with 16% of the cases having a fatal outcome.

These data indicate that special devices are necessary /191 to safely eject the pilot from the cabin of a modern aircraft. The most reliable method for this purpose (as indicated by the large amount of experience with ejection from modern aircraft) is an ejection mechanism (seat) which makes it possible to leave the aircraft in the shortest period of time and at high levels of the air velocity head without the pilot having to make any effort. The pilot may be ejected in the event he is wounded. Unfavorable outcomes in ejection occur rarely and are due mainly to causes which have nothing to do with the mechanism and the action of the ejection system.

At the present time, there are aircraft systems for upward ejection, as well as devices for downward ejection.

The aircraft ejection system consists of a special seat, firing mechanism, and guide rails.

As a result of tests conducted in recent years by Soviet scientists (M. P. Brestkin, P. K. Isakov, V. I. Babushkin, S. A. Gozulov, E. V. Marukhanyan and I. A. Tsvetkov), the effect of ejection on the pilot's body was determined, and a number of recommendations made for developing more efficient methods of ejection and ejection systems themselves.

Upward Ejection

The majority of modern aircraft have seats for upward ejection. The seat is equipped with a firing mechanism. This mechanism is activated by a manual control located on the arm of the seat, or else is operated when a hood contained in the headrest of the chair is pulled down (Figure 45).

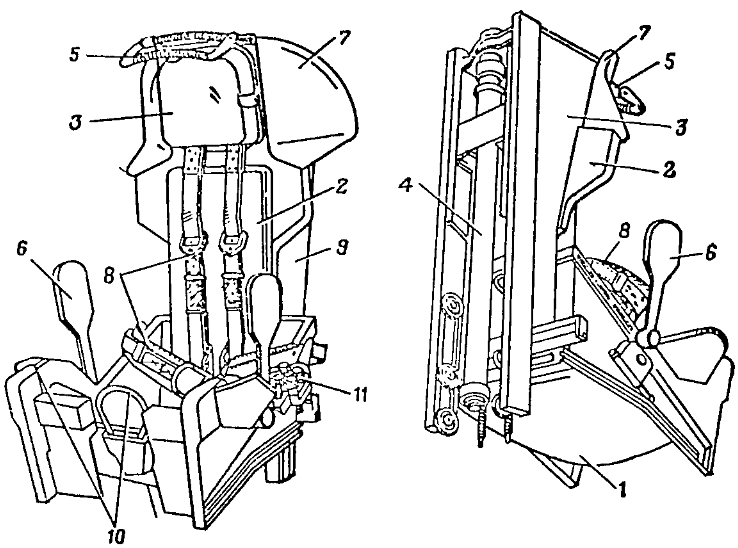

Figure 45. Principal parts of modern ejection seat:

1 - seat bottom; 2 - back rest; 3 - head rest; 4 - firing mechanism; 5 - visor; 6 - restrainer for arms; 7 - stabilizing shields; 8 - straps of restraining system; 9 - parachute system container; 10 - handles to control seat; 11 - common connector.

The explosive energy of the powder cartridge in the firing mechanism must be such that the seat (together with the pilot) is ejected to a height (relative to the aircraft) of at least 12-13 m at a speed of 18-20 m/sec. This enables /192 the pilot at a flight speed of more than 700 km/hr to get away from the sphere of the airflow and not strike the tail assembly. In general, the force required for safe ejection of the pilot depends on the speed and altitude of

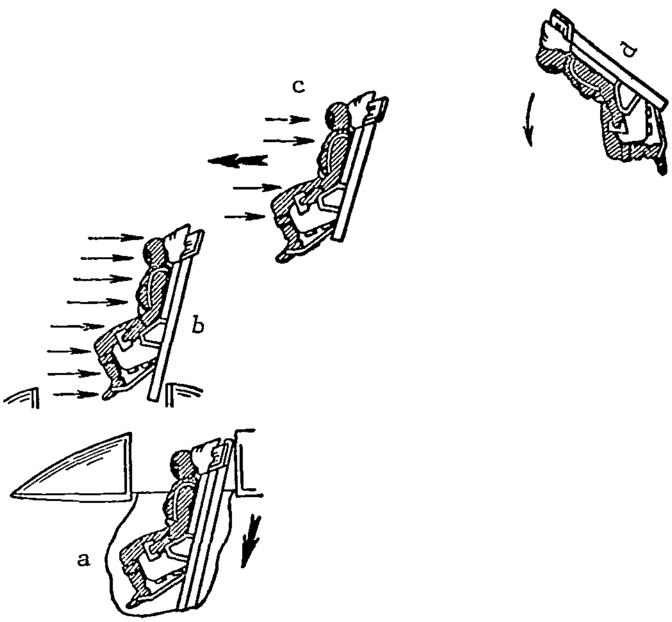

Figure 46. Overload on upward ejection.

flight and the angle of slope of the guide rails, as well as the weight of the pilot and seat.

In upward ejection (relative to the floor of the cabin), the following act on the pilot:

— positive linear shock acceleration, developed on thrust as a result of explosion of the powder charge; the overload acts in the head-feet direction (Figure 46, a);

— pressure (shock) of the incident airflow (Figure 46, b);

— negative linear transverse acceleration, caused by slowing down of the horizontal velocity of the seat due to braking by the airflow;

— overload in the back-chest direction (Figure 46, c); /193

— radial acceleration which develops as the seat turns in the air;

— *the direction of action of the overstress is not constant* (Figure 46, d);

— negative linear longitudinal acceleration, which develops with a drop in the vertical speed of the seat; the overload in this case acts in the legs-head direction (Figure 46, d).

Hence, during ejection, the pilot is exposed for a short period of time to accelerations (overloads) in different directions. At high flight speeds, the accelerations may reach critical values. In order to understand more clearly how ejection acts on the human body, *let us look at the effect of each* of the accelerations that develop during ejection.

Positive acceleration during a thrust in the vertical direction. In the case of upward ejection, at the moment the powder charge explodes, the pilot is subjected to a shock linear acceleration (push) directed from the legs toward the head. In this case, the overload is directed from the head toward the feet, while the degree of acceleration may vary from 10-20 g and the duration of the acceleration effect is only 0.1-0.2 sec. /194

The acceleration necessary for upward ejection may be calculated by the formula

$$a = \frac{v^2}{2S},$$

where v is the speed of ejection of the pilot, and S is the path traveled to achieve this velocity.

For example, let us determine the acceleration, the force of the thrust and the overload in case of upward ejection, if v = 20 m/sec, S = 2 m and the weight of the pilot P = 70 kg. For these conditions, the acceleration will be

$$a = \frac{v^2}{2S} = \frac{20^2}{2 \cdot 2} = \frac{400}{4} = 100 \text{ m/sec}^2 \approx 10g;$$

the force of impact will be

$$F = ma = \frac{P}{g} \cdot a = \frac{70}{10} \cdot 100 = 700 \text{ kg};$$

and the overload will be

$$n = \frac{F}{P} = \frac{700}{70} = 10.$$

Under the influence of this acceleration, the pilot will be pressed against his seat, and the basic stress in this case will be taken up by the spinal column. /195

Experience has shown that an acceleration of 10-20 g, acting for 0.1-0.2 sec, is tolerated completely satisfactorily by the organism. This period of time is insufficient for the development of disorders in the blood circulation, and the disorders in the activity of the central nervous system do not reach the levels that are usual during the long-term action of radial acceleration. Nevertheless, the shock effect of acceleration produces a certain reaction in the organism. At an acceleration of 18 g acting for 0.2 sec, pains are sometimes felt in the buttocks, the sacrum, the chest or neck portions of the spine, and sometimes in the substernal area. In addition, there is a speeding up of the pulse and respiration, an increase in the blood pressure, and a slowing down of response reactions on the part of the body. All of these phenomena pass completely 3-5 minutes after ejection.

During ejection in training, an increase in the pulse rate and respiration, as well as an increase in blood pressure in most cases begins 3-5 minutes prior to ejection. This indicates that these reactions of the organism to ejection develop not only under the influence of mechanical forces (acceleration), but as a result of neuro-emotional stresses connected with the anticipation of ejection to come.

High shock accelerations may cause injury to the spine and other parts of the body. To avoid damage, it is extremely important that the pilot adopt the correct original posture prior to ejection and fasten his body to the chair. If the trunk is not strapped tightly enough to the seat, the effect of the accelerating forces on impact may be multiplied so that it will be directed at an angle to the spine and will cause considerable curvature of its cervical and sacral portions. This may lead to injury of the spine. Despite the fact that the sacral part of the spine is much stronger than the cervical portion, at high overloads and incorrect position of the body in the seat it is the sacral part which is injured. This is explained by the fact that the entire upper part of the body rests on the sacral section (its weight is about 55% of the weight of the body), and only the head rests on the cervical portion. (Its weight is equal to 7% of the total body weight.) Limiting stresses for the cervical vertebrae develop at an acceleration of

27 g, while for the sacral area they develop at an acceleration of 23 g (in both cases, the duration of the acceleration is 0.1 sec, while the rise time for acceleration is up to 345 g/sec). Following sufficient preliminary training, with good fastening of the body in the seat and the correct posture, and with strict observation of all safety measures, a man can satisfactorily withstand an acceleration of 23 g for 0.1 sec. Nevertheless, studies have shown that the maximum physiologically permissible acceleration for upward ejection must be considered to be an acceleration of 20 g with a total duration of 0.15-0.2 sec.

To avoid unfavorable consequences when ejecting, it is recommended that /196 the trunk be firmly fastened to the seat, the head pressed against the head-rest, legs braced against foot rests and hands braced against arm rests. These actions promote the relief of the stress on the spinal column. Thus, for example, merely as a result of resting one's weight on the arm rests, about 30% of the load is taken off the sacral portion of the spine. In order to prevent striking the elbows against the sides of the cabin, it is necessary to press them tightly against the trunk and in no case to extend them to the side.

The safety belts are very important for ejection safety. They must allow the pilot to be fastened reliably to his seat, and must also allow rapid separation from the seat following ejection. It is very important that the tightening of the safety belts (holding the pilot in his seat) be accomplished automatically prior to ejection. Usually the tightening of the belts, removal of the canopy and activation of the firing mechanism are controlled by a single handle.

Pressure (shock) of the incident air flow. This force begins to act at the moment the pilot enters the airstream. Its magnitude depends on the speed of the aircraft (Table 21). As we can see from the table, an individual when ejected may encounter a force of impact from the incident airflow which is /197 hundreds and thousands of kilograms. Since the action of this impact is brief, it may be compared with the action of a linear shock acceleration directed from the chest to the back.

TABLE 21.

Flight speed, km/hr	Airflow pressure, kgf/cm^2	Force of pressure on man, kgf
100–200	50	23
300	235	194
500	1 207	540
600	1 740	1060
800	3 090	1550
1000	4 760	2900
1200	6 940	4850
1300	8 150	—
1400	9 450	—
1500	10 900	—
2000	19 300	8000

Studies have shown that, even at a speed of the airflow, (i.e., flight speed) of 160 km/hr, there is a "trembling" of the skin of the face, neck and ears. As the speed of the airflow increases, the soft tissues of the face are deformed. At a speed of the airflow equal to or more than 500 km/hr, wave-like creases develop in the skin of the face, spreading rapidly away from the corners of the mouth, eyes and chin toward the ears and neck. The soft tissues are deformed to such a degree that the transverse diameter of the face becomes greater than the longitudinal. If air enters the mouth, the cheeks are sharply distended and the filling of the lungs increases. A stream of air at a force of 600 km/hr causes painful sensations in the area of the face, eyes and neck as well as a feeling of pressure in the ears and chest. At an airstream speed equal to 850 km/hr, these phenomena become so severe that isolated hemorrhages appear on the skin of the face and the mucous membranes of the eyes. At an airflow speed of 1,000-1,200 km/hr, extensive hemorrhages and damage to the soft tissue of the face may take place.

The greatest danger is posed by the action of the incident airflow on the unprotected head, as well as the upper and lower extremities. At speeds of 650-750 km/hr, the air stream pulls the hands away from the arm rests, and the legs away from the foot rests. As a result there may be dislocations, stretching of the ligaments in the joints, tearing of muscles, hemorrhaging and so on. Tearing and damage to parts of special pilot equipment is observed at a speed of 640 km/hr, while in some cases it has been observed at lower speeds as well.

All of this indicates that protection of the pilot against the influence of the incident air flow is very important to preserve safety when leaving the aircraft. One means of providing this protection for the face of the pilot is the hood which is mounted on the back of the ejection seat. It also enables him to maintain the correct posture when ejecting. The use of this hood makes it possible to be ejected safely at speeds of 900-1,000 km/hr. However, it is inconvenient to use if the pilot is dressed in a high-altitude /198 compensating suit or flying suit. Therefore, seats with hoods are not used for flights at very high altitudes.

Reliable protection against the influence of incident airflow at flight speeds up to 1,300 km/hr is provided by high-altitude equipment, including compensatory fly pressure suits.

To prevent "scattering" and damage to the extremities when striking the air stream, restraints, supports and limiting devices are used, which are mounted on the seat and hold the hands and legs in the necessary position at the moment of ejection.

In order to leave an aircraft at supersonic velocities, when the impact effect of the incident airstream is particularly great and dangerous, it is desirable to use special deflectors, ejection capsules, and separable cabins.

The deflector consists of a small plate which moves out on a special support ahead of the seat during ejection. Under the influence of the air flow, a shock wave forms in the air near this plate and the pilot falls into a safe zone where the pressure of the incident airflow is much less.

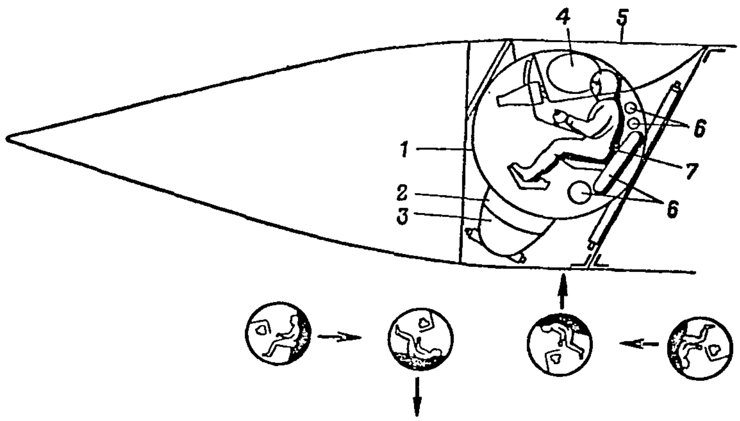

Figure 47. Protective capsule in an aircraft:

1 - wall of antigravity capsule; 2 - parachute system; 3 - ejection system; 4 - hatch; 5 - folding canopy; 6 - equipment; 7 - seat. At the bottom, the positions of the capsule at different directions of the overload are shown.

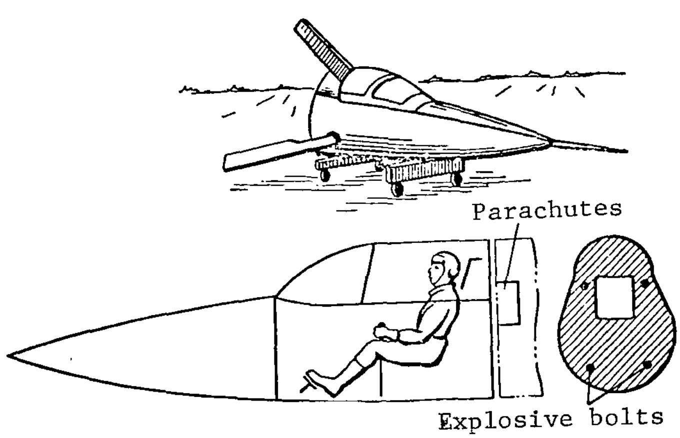

Figure 48. Shape and structure of separable nose section of fuselage containing cabin.

The capsule (Figure 47) consists of a system of flaps which close automatically before ejection /199 forming a closed solid envelope around the pilot.

The separable cabin (Figure 48) separates from the aircraft together with the nose section of the fuselage in the event of an accident in the air.

The ejection capsule and the separable cabin, as well as protection against the impact of the airstream, reduce the negative overload of transverse action. They are capable of floating, and, since they are pressurized, there is no need to use heavy high-altitude equipment.

Negative linear transverse acceleration. This acceleration is the result of the braking action of the incident airflow. In this case, the overload is directed from the back toward the chest. At sonic flight velocities acceleration may reach 40-45 g. It has been found that a healthy individual can withstand an acceleration of this kind completely satisfactorily at a rise time of 500 g/sec.

Negative linear longitudinal acceleration. This develops at the same time as transverse negative acceleration, as the result of extinction of the /200 vertical speed of the ejecting pilot with his seat. In this case, the overload is in the direction from the feet to the head. In the case of ejection from an aircraft flying at a speed of approximately 1,000 km/hr, the acceleration may reach 4 g, and acts for a very short time.

In view of the fact that the transverse negative acceleration is many times greater than the vertical, the direction of their resultant differs slightly from the direction of the transverse acceleration, i.e., from the back-chest direction. The effect of acceleration (total in this case) in this direction, as we know, is more favorable than the action of longitudinal acceleration (less stress on the spine, circulatory system and internal organs) and has no negative effect on the human organism.

In some cases, following separation from the aircraft, the seat begins to rotate around its transverse axis and the pilot begins to be affected by radial acceleration as well as linear negative acceleration. Due to its low magnitude and brevity of action, radial acceleration does not have a significant effect on the human organism.

Downward Ejection

Devices for downward ejection are usually employed in bombers, which have a long fuselage length and a high tail assembly. In this type of ejection, acceleration acts in a direction from the head to the feet while the overload acts from the feet to the head. In the opinion of the majority of investigators, an overload of 8-10 g (with a time of action not in excess of 0.2 sec) must be considered the maximum permissible value for downward ejection.

As we have already said, upward ejection hurls the pilot out of the cabin in his seat. In downward ejection, however, the opposite picture holds: the seat, so to speak, "drags" the pilot behind it. In this case, the overload is transferred to the spinal column of the pilot by means of shoulder safety belts. Therefore, it is recommended that a special system of belts be used in the event of downward ejection which make it possible to hold the pilot's pelvis and sacrum as well as his extremities in the seat.

Downward ejection, due to the directivity of the overload action (feet-head), is less favorable from the physiological standpoint than is upward ejection. /202

Characteristics of Ejection at Low Altitude

The lower the altitude at which the emergency occurs, the more difficult it is for the crew members to take measures to save themselves. The principal difficulty lies in the fact that there is insufficient time (and, consequently, altitude) for filling (opening) the canopy of the main chute. At the present time, parachute systems with short opening times are used for ejection at low and 0 altitudes, and the ejection process is completely automated.

During takeoff or landing, the entire process from the moment of ejection to the moment of landing lasts 4-6 sec and takes place in the following order (Figure 49). The pilot, having decided to abandon the aircraft, pulls out the face curtain (presses the handle of the firing mechanism), the canopy release /203 mechanism is activated at the same time the face curtain is drawn, and 0.5 sec following ejection the "parachute gun" ejects the stabilizing parachute which throws the pilot together with his seat practically on to his back and pulls out the brake chute. About 1.5 seconds later, the clamps of the belt system open automatically, the seat separates from the pilot, and the main parachute is deployed. If the ejection takes place at high speeds, separation of the seat from the pilot and opening of the main chute is automatically delayed by 3-4 sec.

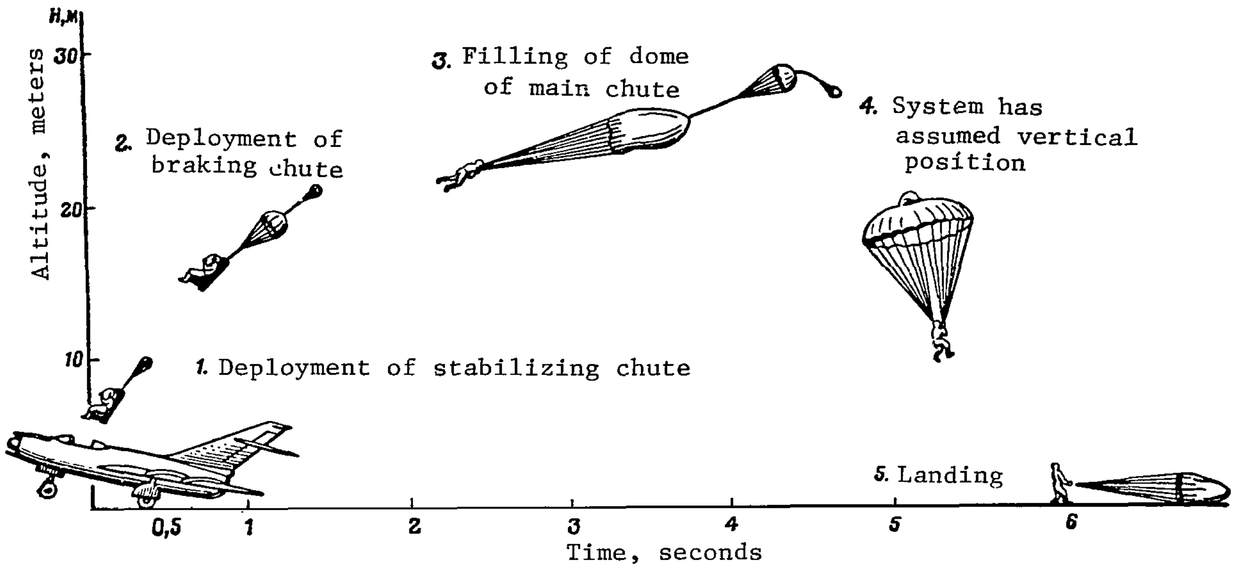

Figure 49. Ejection at low altitudes.

An encouraging new feature intended for rescuing the pilot at low altitudes, judging by foreign data, is the rocket booster (Figure 50). This device, which operates simultaneously with the firing mechanism, hurls the seat together with the pilot to an altitude of more than 90 meters and as a result creates the necessary conditions for operation of the parachute system.

Characteristics of Ejection at High Altitude

If the parachute system is to be operated in the usual order when leaving an aircraft at high altitude, i.e., immediately following ejection, first of all the opening of the parachute will produce a powerful dynamic shock; secondly, considerable time is required for subsequent descent to a safe altitude. As we know, however, a prolonged stay under high-altitude conditions involves the danger of developing oxygen insufficiency in human beings, as well as the effects of high rarefaction, low temperature, and other unfavorable factors. To speed up descent from high altitudes and reduce the forces of dynamic shock, the opening of the main chute is delayed until an altitude of 5,000-3,000 m is reached (Figure 51). On reaching this altitude, the seat also separates. During the descent, the pilot receives his oxygen supply from a parachute device.

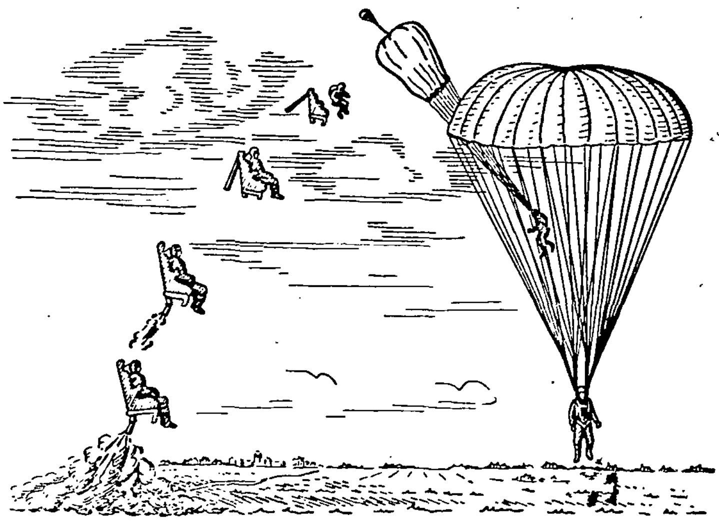

Figure 50. Ejection with rocket booster.

Ejection Training

Ground training considerably facilitates successful ejection in flight. The purpose is not only to teach the pilot how to assume the correct posture and perform the ejection himself, but also to acquaint him with the action of acceleration on the organism and to rely on this method of leaving an aircraft. /205

Training ejection is performed on NKTL-3 trainers (Figure 52) at overloads of 8-12 g. This provides positive results with correct organization of the physical preparation of the subjects, their observation of the work and rest regime, familiarity with the trainer device and how to operate it, becoming familiar with the order of actions to be carried out for ejection, as well as correct organization of training, and complete understanding of the subjects of the effect of the ejection process on the organism. /206

Ground training is carried out with observation of all rules for ensuring the safety of ejection. Special attention must be paid to see that the subjects adopt the established original position and put on their safety belts correctly.

In addition to the NKTL-3, there is another type of trainer which uses the system devised by the engineer Borshchevskiy. This trainer is a universal

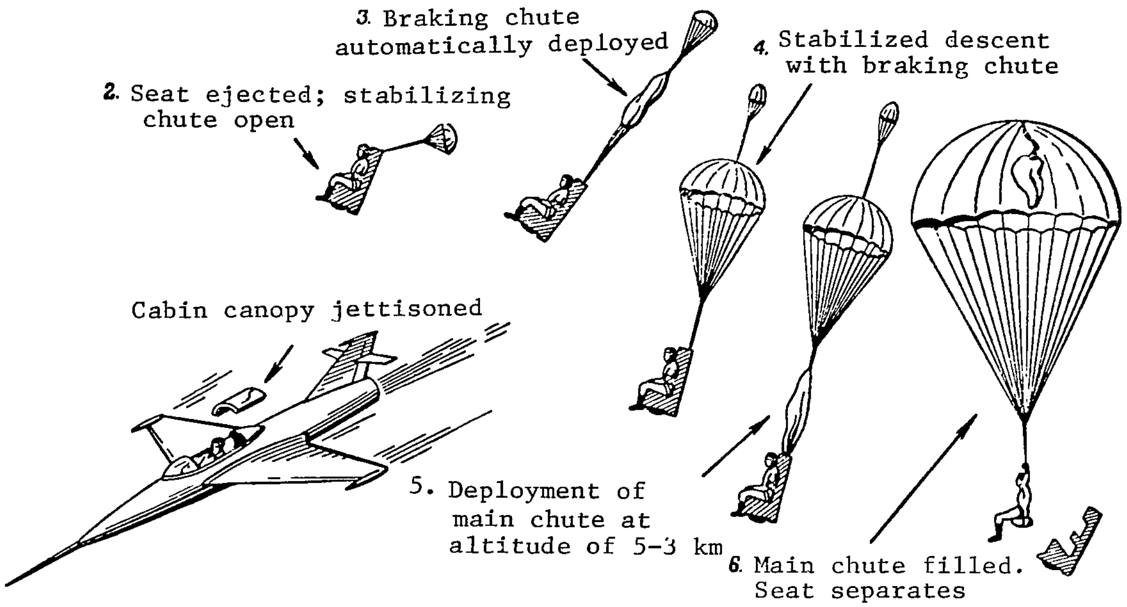

Figure 51. Diagram of ejection and landing by parachute (leaving aircraft at altitude above 5000 m).

type and makes it possible to teach upward and downward ejection. It makes it possible to work on the following elements: assumption of the correct posture, the actions required for carrying out ejection, falling together with the seat, separation from the seat, the technique for opening the parachute, descending with it, turns with the aid of the shroud system, and landing (on land or water).

Effect of Accelerations in a Parachute Jump

As we know, the parachute was invented in Russia in 1911. The inventor's name was G. Ye. Kotel'nikov. The design principles of Kotel'nikov's parachute are used in modern parachutes employed by the air forces of all countries.

The fall of the parachutist, like that of any body, takes place under the action of the force of gravity of the Earth, which imparts an acceleration of

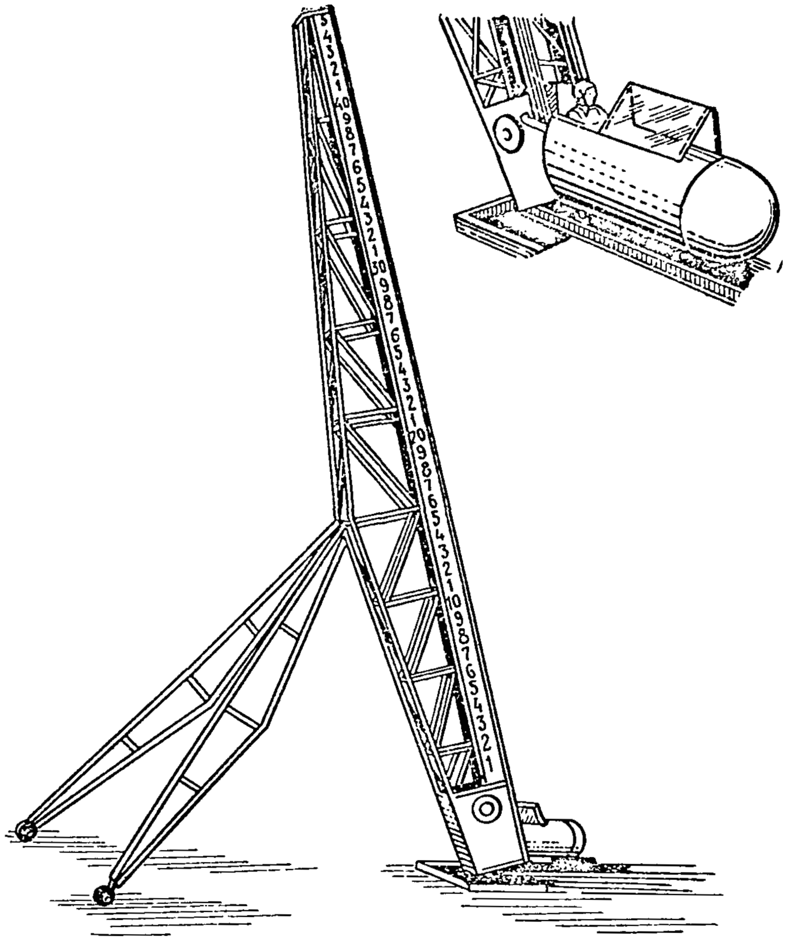

Figure 52. Ejection device for use on the ground.

9.81 m/sec^2 to it. At the same time, the force of the air resistance also acts on it; this is called aerodynamic resistance. This force acts in the direction opposite to acceleration.

The magnitude of the aerodynamic resistance of any body depends on the density of the air, the rate of fall, the size, shape, and nature of the surface of the body. When the speed of fall increases by a factor of 2, the resistance increases by a factor of 4. For the parachutist, the air resistance is a positive factor: the greater it is, the slower the rate of descent, i.e., /207

TABLE 22.

Characteristics of free fall	Altitude at which pilot leaves plane, km										
	1	2	4	6	8	10	12	14	16	18	20
Maximum (constant) velocity, m/sec	50	53	59	66	73	81	90	102	115	132	150
Time to reach it, seconds	12	12.5	14	15	16.5	18	19.5	21	23	25.5	28

the better the parachute can perform its task. In the course of free fall, the force of aerodynamic resistance on the parachute increases due to the fact that air density increases with decreasing altitude. Since this force is directed opposite to the movement of the parachutist, his acceleration begins to decrease at a certain moment. However, when the force of aerodynamic resistance and the force of gravity become equal, acceleration ceases and the parachutist begins to fall at a constant rate. This rate is called the maximum speed of free fall and increases with altitude (Table 22).

Because it has a large surface area (50-60 m^2) and a dome shape, the parachute develops considerable aerodynamic resistance. Therefore, when it opens the speed of fall of the parachute decreases sharply, to about 6 m/sec. At this time, the parachutist also feels a dynamic shock. A negative linear acceleration develops which acts for about 0.1-1 sec. The overload acts in a direction which is favorable to the organism, from the head to the legs. The force of the dynamic shock will increase as the rate of fall of the parachute increases and with increasing area of the parachute as well as with an increasing rate of complete opening. The magnitude of the acceleration (overload) may differ. At high altitudes, the dynamic shock will be much more severe than at low altitudes. This is explained by the fact that its force depends on the /208
actual velocity of the parachutist and is almost independent of the air density. If the parachute opens at an altitude of 1,000 m after falling for

15 sec, the acceleration reaches approximately 6 g, while at 11,000 m it is 18 g. In experimental jumps, foreign investigators have reported an acceleration as high as 21 g.

An acceleration of 8 g is the maximum permissible value for opening of the parachute.

The acceleration and force of dynamic shock may reach very high values if the pilot opens his parachute immediately after leaving the aircraft. Thus, for example, if the pilot leaves the aircraft at a speed of 400 km/hr (110 m/sec) and immediately operates his parachute, the negative linear acceleration will be equal to 10.4 g. The overload developed at such accelerations is dangerous, since in the first place the parachute may tear, and in the second place, the pilot may perhaps be injured. Therefore, after leaving the aircraft, it is recommended to wait a few seconds (if there is enough altitude) before establishing a constant speed of fall, only then opening the parachute.

Studies and practical experience have shown that the overloads that are developed during dynamic shock and are not in excess of the limiting value usually do not cause significant changes in the organism. According to American data, the overload with a dynamic shock must not exceed 20 g with an acting time of 0.1 sec. The duration of the descent by parachute depends primarily on the altitudes at which the parachute opens. Thus, for example, from an altitude of 4-5 km the descent lasts 13-15 min., while from an altitude of 7-8 km it lasts 23-25 min.

The speed of landing is increased when there is a wind, since the parachutist tends to drift. Therefore, instruction jumps with a parachute should be carried out in summer at a wind speed of no more than 6 m/sec, and in winter at no more than 7 m/sec.

At the present time, considerable attention is being devoted to the study of the possibility of rescuing pilots who leave an aircraft at altitudes of 100-200 km. We know that when falling from such altitudes there is a sharp increase in the constant (maximum) velocity of the parachutist, which is explained by the very low air density. Thus, for example, when falling from /209 an altitude of 25 km, this speed does not exceed 200 m/sec, while from an altitude of 100 km it may reach 1,000 m/sec. In the latter case, the pilot will not feel any significant air resistance for about 70 sec. However, when he enters the dense layers of the atmosphere at a high speed, he will feel a sharp braking and, consequently, the overloads will increase. Then the weight of the body will equal the resistance of the air and the overload will become equal to unity. During the fall, the pilot's clothing may be considerably heated by friction against the air. It is considered that the temperature of the clothing may reach 300-500°C in the case of a fall from an altitude of 100 km. Naturally, special clothing is required to protect the pilot against the effects of high temperature.

The rate of descent with an open parachute may be 4 to 10 m/sec; when it is completely calm, this value is equal to 6 m/sec (an individual who has jumped from an altitude of 1-1/2 m falls at the same rate).

At the moment of landing, a negative abrupt linear acceleration will act on the parachutist: at a rate of descent equal to 6 m/sec, this would be approximately equal to 1.8 g, and at a rate of descent of 10 m/sec it would be 5 g. The principal load is then imposed on the soles of the feet. In order to soften ("absorb") the shock and avoid injury, it is recommended that the legs be bent slightly at the knees and a posture be adopted such that the feet are at the same level.

The causes of the injuries that sometimes happen to parachutists are most often some violation of the rules for landing and complexity of landing conditions (strong wind, uneven terrain). As we know from American data, when jumping from an altitude of 10 m and landing on correctly placed (half-bent) legs the soles of the feet were subjected to an overload of 250 g, in which no injury to the joints of the shins and feet was observed. However, if the landing were made with the legs extended, an overload of 65 g was the limiting value. Thus, a linear negative acceleration of an abrupt nature which develops at the moment the parachute opens and during landing will not cause serious functional changes in the organism. One of the pronounced (and, indeed, most important) reactions of the organism to a parachute jump is the neuro-emotional stress, which gradually decreases in the course of training. /210

Catapulting an Aircraft from the Deck of a Ship

When an aircraft is launched from a catapult, the pilot is subjected to a positive linear transverse acceleration. This acceleration is most favorable in terms of its action on the human organism. The forces of inertia in this case will press the pilot against the back of the seat.

Modern catapults intended for launching aircraft from the deck of a ship are 12-30 m long, and have an ejection speed from 105-160 km/hr, and catapulting duration of 0.8 to 1.5 sec. Acceleration under these conditions will not exceed 7 g.

The acceleration on launching from a catapult may be determined by the familiar formula

$$a = \frac{v_c^2}{2S},$$

where v_c is the speed of ejection (catapulting);

S is the length of the catapult.

Let us consider, for example, the acceleration and the force acting on the pilot if v_c = 160 km/hr = 44 m/sec, S = 30 m, and the weight of the pilot P = 70 kg. For these conditions:

$$a = \frac{44^2}{2 \cdot 30} = \frac{1936}{60} = 32 \text{ m/sec}^2 = 3{,}2 \text{ g};$$

$$F = ma = \frac{P}{g} \cdot a = \frac{70}{9.81} \cdot 32 = 224 \text{ kgf}$$

However, under these conditions, if we reduce the length of the catapult to 20 m an acceleration a = 4.8 g, a force F = 336 kg will act on the pilot. Hence, acceleration will depend on the speed of catapulting the aircraft and the length of the catapult: as the ejection speed increases or the length of the catapult decreases, the acceleration will increase.

Thus, when catapulting an aircraft from the deck of a ship, the pilot is subjected to the action of a comparatively small, short acceleration, which acts in the back-chest direction. Acceleration of this kind will not cause any type of problem for the organism.

Effect of Acceleration During a Crash Landing /211

In a crash landing, especially with the landing gear retracted, the length of travel of the aircraft on the runway is considerably shortened due to the considerable braking effect, so that velocity is sharply reduced (sometimes in tenths of a second). In this case, the pilot will be exposed to the action of a negative linear transverse acceleration which very frequently will reach several tens of g.

The magnitude of acceleration in a crash landing of an aircraft may be calculated by the formula

$$a = \frac{v^2}{2Sg},$$

where v is the landing speed of the aircraft, S is the length of the aircraft path (braking path), and g is the acceleration due to the force of gravity.

We will assume that an aircraft which has v = 150 km/hr = 41 m/sec has travelled S = 15 m while making a belly landing. Then the following acceleration will act on the pilot:

$$a = \frac{v^2}{2Sg} = \frac{41^2}{2 \cdot 15 \cdot 10} = \frac{1681}{300} = 5.6 \text{ g}.$$

At the same landing speed, but with S = 10 m, acceleration increases to 8.4 g, while at S = 5 m it will be equal to 16.8 g, and at S = 3 m - 28 g. However, if the aircraft strikes an object at a speed of 150 km/hr and its path length becomes practically zero, the transverse acceleration reaches 84 g. A crash at 400 km/hr means that it will exceed 600 g.

Investigations show that transverse negative acceleration (back-chest) with a magnitude of 5 g and acting for 7-10 min, or a magnitude of 8 g acting for 2 min, will be withstood by subjects without any kind of noticeable changes in the condition of the organism. The same thing is observed at an acceleration of 12 g if the trunk and head are well fixed. Aviation medicine has found that man can also withstand transverse accelerations of higher magnitudes. Thus, for example, we know that in a sitting position he can withstand accelerations up to 15 g for several seconds (in a reclining position, up to 17 g). According to foreign data, transverse acceleration (chest-back and back-chest), gradually increased to 39 g, was withstood completely satisfactorily by the end of the 19th second. /212

Thus, in the event of a crash landing, the transverse acceleration reaching 40-45 g is practically harmless for the pilot, if the clamps of the belt system are properly tightened and fixed for the landing.

Comparatively high resistance of the human organism to the effect of transverse acceleration is explained by the fact that it is directed at right angles to the large blood vessels, and therefore has a very insignificant effect insofar as causing changes in the circulatory system is concerned, which do not have a significant effect on the activity of the central nervous system and other vitally important organs.

In crash landings, there may be injury to the head on some occasions as a result of striking the instrument panel or other projecting parts of the cabin. An incorrect posture on the part of the pilot (especially bending the trunk forward) promotes injury of the spine (Figure 53).

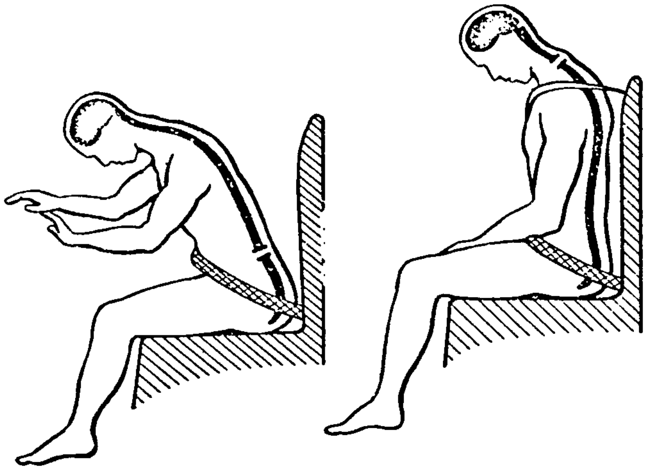

Figure 53. Schematic diagram of spinal fracture with "back-chest" overload.

Prevention of injury to the head and spine during crash landings involves correct use of safety belts, improved design of the system of belts and the seat, the need to use a protective helmet with shock-absorbing devices in the region of the forehead, padding the edges and projecting parts of the cabin with soft shock absorbing material, as well as arrangement of the instruments so that they do not project from the instrument panel. /213

Radial Accelerations

In flight practice, radial accelerations, i.e., accelerations that develop during curvilinear movement of an aircraft, are encountered much more frequently than linear ones.

In the course of flight, a pilot who is performing a maneuver in an aircraft changes the speed and direction of movement. Performance of maneuvers is accompanied by the development of so-called radial or centripetal acceleration. In modern aviation, the magnitude of radial acceleration may reach 8 g with an active duration of up to several seconds and a rise time from 0.5 to 4 g/sec.

If we know the radius of the trajectory r along which the aircraft is moving and the linear velocity of the aircraft v, the radial acceleration may be calculated according to the formula

We can see from this formula that the acceleration is directly proportional to the square of the velocity, and inversely proportional to the radius of the aircraft trajectory.

While performing stunts, the force which causes the acceleration and the radial acceleration itself are directed toward the center of curvature. The centrifugal forces then press the pilot against the seat of his chair. As an example of radial acceleration of an aircraft, we can use the acceleration that develops in a turn. Let us assume that the speed of the aircraft in the turn v = 720 km/hr = 200 m/sec and the radius of the turn r = 1200 m. Then the radial acceleration will be

$$a_c = \frac{200^2}{10 \cdot 1200} = 3.33 \text{ g}.$$

If the radius of curvature is less, the radial acceleration will increase. /214
Thus, at r = 600 m and the same flight speed (200 m/sec) it will be equal to 6.66 g. Acceleration also increases as the flight speed increases. In an aircraft flying at a speed of v = 1080 km/hr = 300 m/sec, at the same radius of the turn (1200 m) the radial acceleration will be equal to 7.5 g.

The maximum radial acceleration is achieved when pulling the aircraft out of a dive (Figure 54). A dive occurs when the aircraft descends at angles from 30 to 90°.

Radial acceleration, like linear acceleration, may act in the direction
from the feet to the head, from the head to the feet, from the back to the /215
chest, from the chest to the back, from the right to the left, from the left to the right. In practice, one most frequently encounters radial acceleration which acts in the feet-head direction.

In performing maneuvers upside-down, as well as when putting an aircraft into a dive from straight-line flight, radial acceleration acts from the head to the feet. In this case, the pilot is pulled out of his chair. This

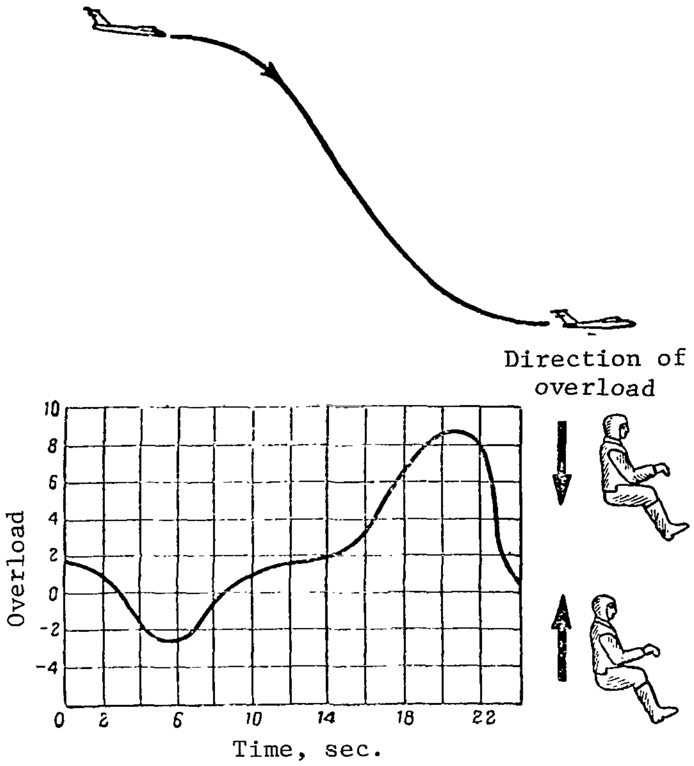

Figure 54. Change in overload during a dive.

phenomenon is used by pilots for emergency exit from the aircraft. Having made the decision to leave the aircraft, the pilot tightens the safety belts and, pushing the control wheel sharply away from him, puts the aircraft into a dive; the centrifugal force which is produced by this action pushes him out of the cabin.

It we know the acceleration, it is easy to determine the centrifugal force by the familiar formula $F_c = ma$. Thus, for example, if the acceleration $a = 7$ g, when pulling out of a dive, a centrifugal force

$$F_c = \frac{P}{g} \cdot 7g = 70 \cdot 7 = 490 \text{ kgf}$$

will act on a pilot weighing P = 70 kg.

In addition, his own weight acts on the pilot. As a result, he is under the influence of a force equal to 560 kg.

The direction of the centrifugal force is always opposite to the direction of radial acceleration.

Influence of Radial Accelerations on the Human Organism

The nature of disruptions in the organism which arise under the influence of radial acceleration depends on its direction, magnitude, rise time, and duration of action. With increased acceleration, the pilot's body and individual parts of it "grow heavy". It becomes more difficult to carry out movements, their coordination is disturbed, there is a deterioration of accurate operation of control devices, and in the final analysis the quality of the pilotage decreases.

With a radial acceleration of 2 g, the pilot usually feels himself pressed against the seat. At an acceleration of 3 g, he experiences a slight difficulty in movement of his hands and feet. It is nearly impossible to leave the aircraft cabin under such accelerations without using ejection. At accelerations of 3.5-4.5 g, the sensation of heaviness in the entire body and /216 in the extremities becomes still more noticeable. In order to hold the body straight, it is necessary to expend considerable force. Under the prolonged influence of such a radial acceleration, there is often a disruption of vision — a grey veil appears before the eyes. At an acceleration of 4.5-5 g, the pilot is under such high stress that he can only carry out slight movements with his hands and feet and his vision is disrupted still further. At accelerations of 5-5.5 g, it becomes extremely difficult to make movements and a black veil appears before the eyes; there is a disruption of the rhythm and depth of respiration, and the pulse speeds up. At an acceleration of 6 g, there may be a sudden loss of consciousness. After the action of the acceleration ceases, consciousness returns rapidly, but its clarity remains disrupted for a short period of time.

A characteristic change under the influence of radial acceleration is disruption of the cerebral cortex function due to disturbance of the blood supply to the brain.

Radial acceleration acts on a seated pilot in the feet-head direction, coinciding with the direction of the large blood vessels; the blood moves in the direction of action of the overload. As a result, it overfills the vessels of the lower extremities and the abdominal cavity. It has been found that 1/4 or more of all the blood in the organism may be concentrated here.

It has been established experimentally using animals that the blood pressure in the vessels of the head decreases on the average by 20-30 mm Hg for each unit of acceleration. This pressure drop, caused by the inertia of the blood, begins about 0.5 sec after the beginning of the acceleration. The drop in pressure and the reduced amount of blood filling the heart causes reflex acceleration of the pulse. In man, at an acceleration of 5-5.5 g, the pulse rate may increase to 120-180 beats per minute.

The movement of the blood in the circulatory system causes stimulation of a great many nerve endings within the walls of the blood vessels. The flow of nerve impulses which results reaches the central nervous system and sets off a number of reflex reactions that are aimed at restoration of blood circulation. At low accelerations, lasting a short time, these reflex re- /217 actions normalize the blood circulation, and no injurious effects on the organism result.

As the organism adjusts to the effect of acceleration, an important role is played by the organs of respiration, whose activity is very closely related to the work of the cardiovascular system.

Under the influence of acceleration, together with an increase in cardiac activity, as a rule there is an increase in pulmonary ventilation. At low accelerations, it increases due to the depth of respiration. However, if acceleration reaches 4-5 g or more, respiration becomes difficult, its rhythm may be disrupted, and the depth increased. In such cases, pulmonary ventilation increases due to the acceleration of respiration. When acceleration reaches significant values and acts for a longer period of time, the effectiveness of compensatory reactions becomes inadequate. A severe oxygen starvation of the cells in the central nervous system develops, accompanied by a retardation of response reactions, disruption of memory, disorganization of coordination of movements, weakening of msucle strength, disruption of the feeling of muscular force, etc. The most dangerous thing is loss of consciousness, which may be preceded by a short period of confusion. Loss of consciousness may occur at an acceleration of 5-6 g, acting for more than 3 sec. The flight crew must always remember that consciousness in such cases begins to return 10-15 sec after the end of acceleration. After it has been regained, the individual is still not in a state to orient himself and correctly evaluate the situation for 20-30 sec (and sometimes longer). Consequently, for a rather long time the pilot cannot control the aircraft, and the outcome in such a situation may depend on the flight altitude at which the loss of consciousness took place.

As we have already said, it is possible in flight practice to have an influence of radial acceleration directed from the head to the feet (negative overload). In such cases, even at an acceleration of 1.5 g, the sensation of flow of blood to the head is felt. At an acceleration of 2 g, the vision is easily clouded, pain appears in the area of the eyes, there is a flow of tears and sometimes dizziness. At accelerations of 2.5-3 g, the sensation of /218
blood flow is even further increased, respiration becomes difficult, a red fog appears before the eyes, and sometimes there is hemorrhaging from the nose. At an acceleration of 4 g, a pronounced flow of blood to the head is felt, severe pains occur in the eyelids, the flow of tears increases, all surrounding objects appear to be bathed in red light, the skin of the face is red and edematous, numerous local hemorrhages appear on the skin of the face and the mucous membranes of the eyes, and, finally, there are sharp pains in the head, as well as confusion in the mind. As in the acceleration from feet to head, the basis for these phenomena lies in the disruption of the blood circulation. In this case, the blood moves into the vessels of the upper part of the body and brain. As a result, the blood pressure in these vessels becomes more significant as the radial acceleration increases. Negative overloads (feet-head) are withstood by the pilot with much more difficulty than positive ones.

Limit of Toleration to Radial Acceleration

It is only with high resistance to the effect of acceleration that the pilot can completely use the military capabilities of modern aircraft.

Acceleration which does not cause significant disruptions in the organism or which causes insignificant and transitory disruptions is considered to be tolerable. Since it is primarily disruptions of vision that occur under the influence of acceleration, acceleration in which a gray fog appears before the pilot's eyes is considered to be the maximum tolerable acceleration.

As a result of studies that were conducted with centrifuges and under flight conditions, reliable data have been obtained, on the basis of which we can get some idea of the magnitude of tolerable radial acceleration and the factors which affect tolerance. Such factors include magnitude of acceleration, rate of increase, direction and duration of action, as well as individual characteristics of the organism.

According to the data of Soviet investigators (D. Ye. Rozenblyum, V. G. Mirolybov, P. K. Isakov, I. K. Sobennikov, D. I. Ivanov, I. Ya. Borshchevskiy, V. I. Babushkin, et al.), a pilot in a sitting position can withstand a radial acceleration with a magnitude up to 6 g, acting from the feet to the head, for 1-2 seconds, completely satisfactorily, without disturbance of vision, com- /219 pletely retaining his working ability. In flight, properly physically trained experienced pilots can withstand satisfactorily accelerations of 7-8 g, while in individual cases this can go as high as 9-9.5 g with a duration of up to 1 second. On centrifuges, they can completely successfully withstand accelerations up to 4 g, sometimes for as long as 3 minutes. But if the radial acceleration acts for a longer period of time, the changes in the functions of the organism will appear at much smaller values. Thus, for example, with an acceleration duration up to 10 seconds for an untrained individual, problems with vision will occur at 3-4 g and vision will be completely disrupted at 4.5 g, with loss of consciousness occurring at 5.5-6 g.

Tolerance to acceleration is also affected by the state of the neuropsychic sphere. For example, a pilot who is flying an aircraft can withstand acceleration better than a pilot who is sitting as a passenger, since the first is in a state of readiness for the action of acceleration and accommodation reactions occur more rapidly and more completely in him.

The limits of tolerable radial acceleration for different individuals may differ and depend on many factors. But for any conditions, the duration of acceleration is of primary importance: the shorter the time of acceleration, the more easily it is withstood by the human organism. As we have already said, the human organism can withstand linear acceleration up to 20 g for 0.1-0.2 seconds without noticeable disturbance of vision or function of the central nervous system.

Resistance of the organism to radial acceleration, acting in the direction from the head to the feet, is much less than to acceleration directed from the feet to the head. This resistance also increases significantly if the acceleration acts at an angle which is perpendicular to the longitudinal axis of the human body. Under the influence of acceleration at an angle of 45%, tolerance increases by 1.5 to 2 g. In a reclining position, an individual in a centrifuge can withstand radial accelerations of 14-16 g for several tenths of a second. The significant increase in the resistance of the organism to radial acceleration in the reclining position is explained by the fact that the latter, acting in the chest-back direction (back-chest) disrupts the blood circulation /220
and bothers the internal organs to a lesser degree than in the sitting posture.

The resistance of the organism to acceleration decreases significantly under conditions of oxygen starvation, during overheating of the organism in flight and before flight, after recovery from an illness, with over-fatigue, following the use of alcoholic beverages and considerable smoking, following long interruptions in flying practice, with neuro-psychic complications, etc.

Studies have shown that under the repeated influence of radial acceleration there sometimes develop cumulative phenomena which take the form of fatigue, increased tendency to perspire, sleep disorders, deterioration of ability to withstand subsequent flights as a pilot (A. P. Popov, Ye. A. Derevyanko, D. I. Ivanov, et al.).

We know that accelerations that develop when piloting aircraft at supersonic velocities increase not only in terms of magnitude, but in time of action.

The human organism, thanks to its compensatory reactions, can adjust to acceleration. However, its ability in this regard is not unlimited. This forces aircraft designers and specialists in aviation medicine to find ways of increasing the limit of tolerance to radial acceleration.

Measures Which Increase Resistance of the Organism to Radial Acceleration

Among the most effective measures involved in increasing the resistance of the organism to the action of radial acceleration are the following: observation of the proper regime of work, rest and eating and physical exercises and flight training, as well as the use of antigravity devices, seats with adjustable back angle, etc.

Measures of a general nature. Resistance of the pilot's organism to acceleration depends primarily on his general condition. Therefore, strengthening the general health condition of flight personnel must be one of the principal tasks of the commanders and aviation doctors.

The members of the flight crew must always remember that observation of /221 the correct daily schedule, the regime for work, rest and eating promotes an increase in the resistance to the action of radial accelerations. Flights should never be made with any illness, in a state of neuro-psychic stress, over-fatigue or after insufficient sleep, excessive smoking, use of alcohol, sexual excess, etc.

In conjunction with the fact that resistance to radial acceleration deteriorates under conditions of insufficient oxygen supply to the organism, the oxygen equipment must always be kept in good repair and the rules for putting on high-altitude equipment must be carefully observed; the cabin must also be carefully checked to insure that it is correctly pressurized.

To avoid overheating of the organism, it is necessary to maintain an established temperature regime in the cabin. Sometimes the surface blood vessels will dilate as a result of overheating, and this promotes an increased drop in blood pressure under the influence of radial acceleration. In order not to cause a deterioration of the tolerance to radial acceleration, it is also forbidden to carry out flights on an empty stomach or immediately after eating a heavy meal. It has been found that, when an eating schedule is followed, resistance of the organism to acceleration increases by 1.5-2 g.

Physical Preparation. We know that physically strong pilots, who systematically take part in various sports, are more resistant to the effects of ıadial acceleration. Therefore, the physical training of the flight crew must strengthen the total physical state and train regulatory mechanisms of the circulation.

On this level, it is very effective to have physical exercises that are designed for training the cardiovascular system and nervous regulators of blood circulation, as well as the muscles of the abdominal press and lower extremities. Therefore, in addition to mild atheltics and sport, gymnastics should play a part (rotating swings, gymnastic rings, wall bars, horizontal bar). It is also recommended that the crew go skiing, horseback riding, and swimming.

During athletic exercise and special training, attention should be paid to correct breathing. It is very important to learn to shift respiration from the abdomen to the chest, since under the influence of acceleration the muscles of the abdominal press are subjected to stress and abdominal respira- /222 tion is limited.

Organized physical exercise must be one of the most important aspects of increasing resistance of the pilot to the effects of acceleration.

Flight Training. Systematic flight training is the most important factor which increases the resistance of the organism to acceleration. It provides extremely valuable results in the form of a gradual increase of speed and complexity of flight. In the course of flight, not only does the pilot carry out exercises and learn about the technique of piloting, but he also trains his cardiovascular system and the neuroreflex mechanisms which regulate blood pressure.

In the course of flight training, the pilot becomes accustomed to the effects of acceleration, acquires the ability to evaluate correctly his state during acceleration and to relate calmly to this effect. In addition, the pilot develops conditioned reflexes, so that even before acceleration develops compensatory mechanisms begin operating in the organism which are able to improve the tolerance to acceleration.

Antigravity Devices. The development of antigravity devices in the USSR and abroad has been going on for a long time. The operating principles of the devices involve the creation of pressure in the area of the stomach and lower extremities, so that when radial accelerations develop there will be resistance to the movement of blood from the vessels in the upper part of the body into the lower part.

Antigravity suits of the pneumatic type (Figure 55) are the ones most widely used. They consist of a wide girdle (chamber) applied in the area of the stomach, pelvis and shins. All of these sleeves are connected together and attached to a special regulator which forms part of the system for ventilating the aircraft cabin. When the effects of radial acceleration begin, the pressure in the cuffs is automatically increased to the required level. As we have already said, antigravity devices are frequently incorporated in high-altitude compensating flying suits.

The pressure in the chambers of the antioverload suit is increased with the aid of a pressure regulator to 50-55 mm Hg for each unit of acceleration, /223
reaching 450 mm Hg. Then the pressure remains constant, although the acceleration may increase further.

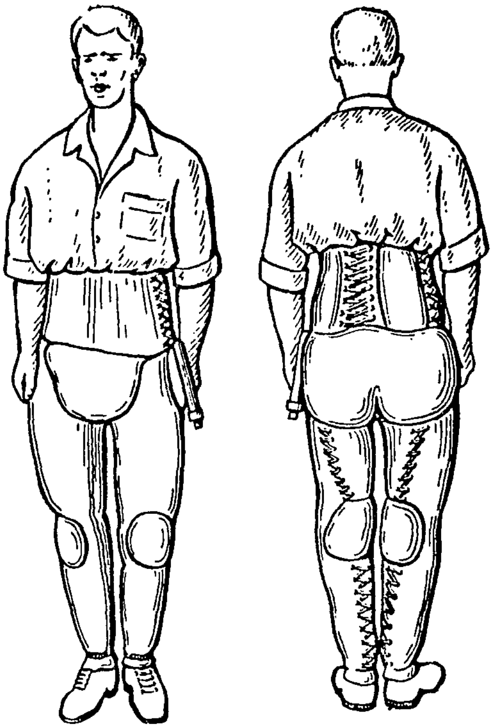

Figure 55. PPK-1 antigravity suit.

The principal condition for an effective antigravity suit is careful fitting to the dimensions of the pilot's body. The use of the suit increases the tolerance of the pilot to radial acceleration by 2-3 g.

Position of the Body. As we have already pointed out, tolerance to radial acceleration increases markedly if it acts in the chest-back or back-chest direction. Consequently, by changing the position (posture) of the pilot in the cabin, we can considerably increase his resistance to the action of radial acceleration (Figure 56). /224
Thus, for example, in the "cowering" position, the internal organs are somewhat compressed and the intra-abdominal pressure increases. This prevents inertial shifting of the blood into the vessels of the abdominal cavity and the lower extremities, and creates more favorable conditions for the blood supply to the brain. Resistance to acceleration is increased by as much as 1.5-2 g. The use of this posture has not yet been put into practice, however.

Tolerance to radial acceleration also increases when changing the slope of the back of the seat backward, so that the direction of acceleration becomes almost transverse (chest-back). Experiments have shown that, when the back is tilted backward by 30°, the tolerance increases by 1.5-2 g, while at a slope angle equal to 85° an acceleration of 15 g can be withstood /225
satisfactorily.

Tolerance increases if the back is placed perpendicular to the direction of acceleration.

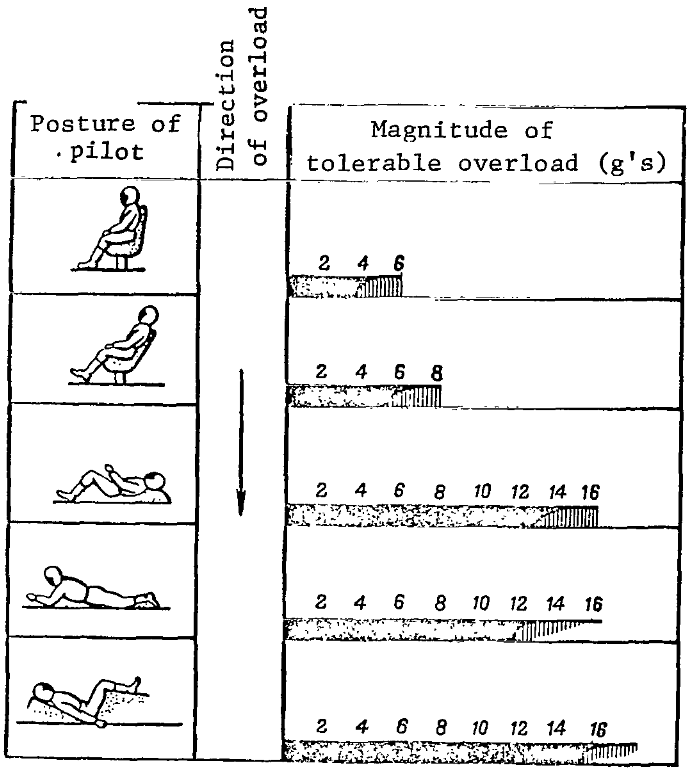

Figure 56. Effect of the position of the body on ability to withstand overloads.

It is possible that future improvement will provide a seat with an adjustable back angle. However, this will complicate the pilot's work. At the present time, the technical difficulties and conditions for installing such a seat for pilots in the cabin has not yet been built.

Angular Acceleration and Coriolis Acceleration

Angular Acceleration. This develops when the angular velocity of motion changes (for example, when carrying out a maneuver). The change in the angular velocity per unit time is called the angular acceleration. It is usually expressed in radians per second squared (rad/sec^2).

Coriolis Acceleration (rotary acceleration perpendicular to the trajectory). This develops with any change in the pilot's position during curvilinear movement of the aircraft. The simplest example of the action of rotary acceleration is the tilting of the pilot's head when turning the aircraft around its lengthwise axis (roll).

Angular and rotary accelerations are specific stimuli of the vestibular apparatus. When carrying out a maneuver, these accelerations are insignificant in the majority of cases and will not cause noticeable vestibular problems, but in some people they can cause unpleasant sensations (dizziness, nausea).

CHAPTER VIII

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INFLUENCE ON THE PILOT'S BODY OF FLIGHTS UNDER DIFFICULT CONDITIONS

Flights under difficult conditions may be assumed to be those which are carried out under difficult meteorological conditions, as well as night flights.

Flights Under Difficult Meteorological Conditions

Flights under difficult meteorological conditions are those which are carried out with complete lack of visibility of the natural horizon, terrestrial, and celestial landmarks or with limited visibility of the latter. They include day and night flights in clouds and outside of clouds, with low cloudiness and limited visibility, in heavy rain or snow, or in the stratosphere (at altitudes above 15 km). Flights under these conditions are carried out completely or partially on instruments. When flying on instruments ("blind" flying), the pilot determines the position of his aircraft in space, as well as his location with the aid of piloting and navigational instruments. On such flights, the working conditions for the pilot place greater physical and neuropsychic demands on him and also call for a higher degree of pilot training.

As we have already noted, an individual gets an idea of the external medium around him through sensations which are a reflection of the properties of objects and phenomena in the material world, acting directly on the sense organs. Through sensations, the individual recognizes in particular the movement and position of his body in space. His understanding is made up of sensations.

In his work "Materialism and Empiriocriticism", V. I. Lenin wrote: "While /227 sensation of time and space can provide man with biologically directed orientation, it is only under the condition that these sensations reflect the objective reality outside the individual: the individual cannot relate biologically to the medium if his sensations do not give him an objectively correct idea of it." (Collected Works, Volume 14, Page 166).

We also know that man, who has been under the influence of the Earth's gravity during a long period of evolutionary development, has developed specific psychophysiological mechanisms which make it possible for him to maintain his balance and orient himself in space on the basis of sensations of the position of his body.

Hence, the ability of man to detect spatial position has developed as a result of the activity of many complex analytical systems (analyzers). The leading role among these is played by the visual analyzer (vision). In addition, the function of orienting the position of the body in space is accomplished with the aid of the vestibular, motor, and tactile analyzers.

Under ordinary conditions on the ground, an individual is able to determine his position in space quite easily. This ability is acquired by him in early childhood, and develops all during his life. We know, for example, that an individual with closed eyes, i.e., without participation of the visual analyzer, can sit in a chair, stand up, turn to the right or left. Consequently, in order to determine the position of his body under conditions to which he has become accustomed (without changes in gravitation acting on him) it is sufficient to have the participation of the vestibular and motor analyzers.

However, the psychophysiological process of determining the spatial position of the aircraft is much more complicated in flight. Here vestibular stimuli and muscle sensations alone are insufficient. In many cases, they may even be the source of false spatial sensations. Therefore, when making flights under difficult conditions, the pilot must be guided only by the readings of his instruments, not depending on his sensations and frequently acting against them.

Numerous experiments indicate that learning to determine correctly the position of an aircraft in flight by instruments depends essentially on knowing how to read them. This knowledge develops in the course of ground and flight training. The technique of piloting also depends on the ease of reading the instrument panel. /228

Instrument flight differs from ordinary flight in that the spatial position of the aircraft is determined by the pilot, not on the basis of a natural horizon and ground landmarks, but indirectly, as a result of evaluation and synthesis of the readings of the piloting and navigational instruments.

Piloting is complicated when flying on instruments. Longer times are required to determine the position and the nature of the movement of the aircraft in space, than in visual flight, and so it becomes necessary to carry out a number of additional calculations, and so on.

During flight under difficult meteorological conditions, it is necessary to take into account the unfavorable effect of sharp changes in light intensity on the visual function of man. Such changes are observed, for example, when passing through clouds, moving upward or downward. In both cases, the sharp contrast between the light intensity above the clouds and that beneath them forces the pilot's vision to adapt. As a result, the visual analyzer and nervous system undergo considerable stress and are fatigued. In addition, a certain period of time is required to regain normal vision under new conditions of illumination. It is easy to understand how important it is to take this into account in modern aircraft. For example, when emerging beneath a cloud into overcast weather, visual determination of altitude and recognition of terrain will be impeded during the period of time required to adjust vision.

Light intensity also changes with altitude. While on sunny days in middle latitudes the brightness on the ground reaches 80,000-100,000 luxes, at altitudes of 3,000-30,000 m it is equal to 130,000-140,000 lux. On overcast days on the ground and in the clouds, it is only 4,000-6,000 lux. Intense brightness tires the vision, and calls for using special light filters when flying at high altitudes. In addition, at these altitudes there is a sharp contrast between shadows in the aircraft cabin, which makes it more difficult to observe the instruments. /229

During flights under difficult meteorological conditions, the weather may change rapidly. Its instantaneous deterioration causes serious difficulties in piloting and, increases the neuro-psychic stress on the pilot.

Instrument flight consumes a lot of energy and effort on the part of the pilot, more than any ordinary flight. With insufficiently trained pilots, fatigue appears after only 30-40 minutes of flight. It most frequently takes a form in which the pilot, without noticing it himself, begins to make errors in piloting; he becomes sluggish, apathetic, sleepy, etc.

As we know, a pilot flying on instruments must simultaneously monitor the readings of a great many instruments. Therefore, it is very important (in order to reduce stress) to mount the instruments on the instrument panel and the sides of the cabin in a correct and efficient manner. In addition, it is necessary for the pilot to be located comfortably in the cabin and to see the instruments clearly; otherwise, unpleasant sensations may arise which promote the appearance of erroneous concepts or illusions, disturbing the performance of the flight.

Illusions are erroneous concepts about the spatial position of the aircraft, which develop in flight with the absence of visibility of the ground and horizon. In some cases, they become so severe that the pilot doubts the correctness of his instrument readings. Ceasing to trust his instruments, he may lose his spatial orientation and get into a serious situation.

Erroneous ideas during flight on instruments are the result of disruption of coordination in the operation of the analyzer systems which carry out the function of spatial orientation. Illusions of this kind are physiological.

Erroneous concepts are highly diverse. Thus, for example, it may seem to the pilot that the aircraft is flying tilted to one side, gaining altitude at a steep angle (pitching up) or diving, climbing or descending while making a turn, flying upside down, turning in the opposite direction after coming out of a turn (illusion of turning in the opposite direction), etc. Similar illusions develop in pilots who do not have training in instrument flying: /230

— on night flights under difficult meteorological conditions;

— during flights under conditions of high atmospheric turbulence (in rough weather);

— during flights in clouds which have different brightness or density;

— during a long glide, sharp entrance into curvilinear flight and emergence from it;

— intensive acceleration or braking;

— upon sudden entrance into clouds.

Illusions may arise when beginning to fly on instruments, following long interruptions in such flights, or during a long flight when the pilot begins to feel fatigued. In the case of pilots who are well-accustomed to flying on instruments, illusions develop more rarely and may be coped with easily.

Incorrect sensations may occur in anyone, but their degree differs. For example, in most fighter pilots incorrect sensations usually last no more than 5-6 seconds, while untrained pilots or pilots who have had a long interruption in flying on instruments may have illusions that last as long as 12-18 seconds, or several minutes in certain cases.

Loud crackling and noise in the earphones which develop during lightning flashes and other disturbances increase the strength of the illusions and may sometimes actually cause them.

Illusions about spatial position also include "psychological" or visual illusions. Illusions of this type develop as a result of distorted perception of light, landmarks or objects. For example, stars may be interpreted as navigation lights, or fires on the ground may be seen as stars. They may also occur when looking for landing lights from a great distance. Illusions of an increase in flight altitude, distortion of the shape of objects located outside the aircraft, and distances to them may develop due to refraction of light rays caused by rain and snow, as well as clouds and thick haze.

In heavy rain, clouds, fog and thick haze, as a result of refraction of the rays of searchlights or aircraft lights, a light "screen" may appear in front of the aircraft or on the cabin windows in the form of patches (light spots). The screen and spots may cause visual illusions of a change in the spatial position of the aircraft and the appearance of "obstacles" before it. The visual illusion may develop in flights above clouds or between layers of clouds when the sloping line of clouds is taken as the natural horizon. This same illusion may develop when flying over mountain ranges. /231

In order to prevent the development of illusions in flight, it is recommended that:

— training be carried out on ground trainers and special models;

— long interruptions in instrument flying not be allowed;

— a specific program of teaching instrument flying be observed;

— a correct regime of work, rest and eating be maintained;

— participation in physical culture and sport be encouraged (special attention being given to training the vestibular apparatus as well as the cardiovascular and neuromuscular systems).

Night Flights

Night flights are those which take place during the period between sunset and sunrise and at dusk. The aircraft is piloted primarily on instruments.

Red or ultraviolet light is used to illuminate the cabin and the instrument panel.

Night flights, as well as flights under difficult conditions in general, force the flight crew to be subjected to a high degree of neuropsychic stress.

Visibility at night depends on natural illumination, the nature of the clouds, the state of the weather and the nature of the terrain. With a full moon in clear weather, actual illumination is equal to 0.22 lux, while on a moonless night with dense clouds it may be 0.0002 to 0.0003 lux. At night, lakes and rivers can be seen (in summer), as well as railroads, highways, forests, populated areas, and sometimes country roads. Light beacons are clearly visible, as well as beams of searchlights, and so on.

One of the characteristics of night flights is the disruption of normal diurnal periodicity in the activity of the body. In the normal rhythm of life, the day is reserved for active movement and the night for rest. Usually the intensity of physiological processes in the body is somewhat lower during the night than in the day.

It is natural that the transition to nocturnal activity initially has an /232
unfavorable effect on the emotions and working ability of man. However, in the course of time the organism becomes accustomed to the new rhythm. A suitable example of this is offered by individuals living under conditions of polar day and night. During the first days and even weeks, their working ability is reduced and there is a feeling of breakdown. Later, however, their condition becomes completely normal.

While making night flights, it is very important to organize correctly the preflight and postflight rest programs for the flight crew.

During night flights, extremely high requirements are imposed on the vision of the pilot, especially his night vision — the ability to see with reduced illumination.

As we have already stated (see Chapter III), the process of visual perception begins in the retina of the eye, or to be more exact, in its light-sensitive nerve cells, the rods and cones. It terminates in the visual center of the cerebral cortex, where a visual image is formed. Under the action of light, the molecules of rhodopsin in the rods and the molecules of iodopsin in the cones break down.

The nerve impulses which arise due to the breakdown of the molecules of rhodopsin and iodopsin (bioelectric currents) travel along the nerve fibers to the visual center of the cerebral cortex; their frequency increases with the volume of light striking the retina. Under ordinary brightness conditions, the frequency of these impulses will not exceed 300 per second.

At illumination greater than 30 luxes, only the cones function (daytime vision), while at brightnesses less than 0.03 lux it is only the rods which function (night vision). This is explained as follows: When brightness in- /233 creases, the process of breakdown of molecules of rhodopsin in the rods is intensified, while the formation process deteriorates. As a result, the rods cease to operate in the daytime, since rhodopsin is practically completely absent from them, and only the cones function, whose iodopsin is restored much more rapidly.

In making the transition from bright light to darkness, the rods cannot renew their activity immediately; they require a short time to become accustomed (adapt) and to store up rhodopsin. The process of accumulation grows longer as the brightness prior to the transition to darkness increases. As the rhodopsin is restored to the molecules, sensitivity of the retina to light is also restored. The pupil dilates on entering darkness. While the diameter of the pupil in bright daylight is 2 mm, it expands to 8 mm in darkness, i.e., the area of the pupil increases 16 times. This increase is the result of light flux acting on the retina.

Accommodation of the eye to darkness is called dark adaptation. The basis of this process is the increase in sensitivity of the eye to light. Thus, for example, after being in darkness for an hour, the sensitivity of the eye may increase by 200,000 times in comparison to the original level. Therefore, even under nocturnal conditions when the pupils of the eyes have expanded and sensitivity is very great, with a rapid transition to bright light (for example, unexpected entry into the beam of a searchlight) there is a temporary but important disruption of vision. In general, under conditions of marked contrast in illumination, visibility is disrupted and orientation in space becomes more difficult; this is observed in particular in making the transition from reading the instruments to observing the situation outside the cabin, and vice versa.

The difficulty in night flights lies in the fact that during weak illumination the visibility of ground landmarks is limited, especially in bad weather. Under wartime conditions, it is difficult to carry out visual orientation due to the lack of lighted landmarks (cities and populated areas are blacked out).

At night, under conditions of poor illumination, the following changes in vision are observed:

— there is a sharp drop in the acuity of vision (up to 0.3-0.7 on a bright moonlit night and up to 0.05-0.03 on a cloudy moonless night);

— visual estimation of depth deteriorates, and it becomes more difficult to estimate distances to objects and their mutual positions;

— there is a disruption of color vision, so that all colored objects appear gray under nocturnal illumination;

— the field of vision is restricted.

In order to improve night vision for night flying, dark adaptation is required beforehand. As a result of adaptation, there is a sharp increase in the ability of the individual to differentiate poorly illuminated objects. It is believed that 20 to 25 minutes are required to adapt the eyes to darkness; complete adaptation is accomplished in 1 to 1-1/2 hours.

When carrying out night flights, the pilot must adapt himself:

— when going out to take off;
— after flights in the beams of searchlights;
— when descending from high altitudes (vision may deteriorate due to oxygen starvation).

Following dark adaptation, the eyes are more sensitive to green light and less sensitive to red light. Blue and yellow light occupy an intermediate position. When the eyes are adapting to bright light, the point of maximum sensitivity is the central depression in the retina. At this point, yellowish-green light appears brightest while red is least bright, as it is following dark adaptation. On a night flight, under the influence of a number of factors, the adaptation processes slow down.

On night flights, it is necessary to pay special attention to the cabin illumination. The illumination must not disrupt dark adaptation; it must allow the pilot to work with the equipment without stress on his vision. It must be possible to differentiate clearly between the readings of the instruments, to read the flight chart, and to carry out observations of the surroundings. Illumination in the cabin must be between 0.5 and 10 luxes, and be smoothly adjustable, depending on the natural illu nation.

As a rule, reflected light is used for illumination of the cabin. Direct rays from a light source must not be allowed to strike the pilot's eyes, and the formation of light reflections on the lenses of instruments and the canopy must be prevented.

For the best visual perception, the instrument panel and the dials of the instruments are colored flat black, while the walls of the cabin are dark gray. It would seem that yellowish green should be used for marking the scales of the instruments, since night vision is most sensitive to this color. However, studies have shown that this color is detected poorly at low illumination levels in the cabin. /235

As we have already said, night vision has low sensitivity to red light. Therefore, red (or ultraviolet) light does not disrupt dark adaptation, and the pilot's vision retains a high level of sensitivity. He can see the instruments clearly, we well as objects and signals outside the cabin. This is explained by the extensive use of red or ultraviolet light for illuminating the cabin.

The illumination of the area in which the flight crew is located prior to going on night flights is also important for the quality of night vision. Illumination must be as uniform as possible without extreme contrasts and not blinding. It is desirable to use illumination with red light; this shortens the time to adapt to the dark and does not fatigue the vision. All light sources in the flight crew's quarters must have frosted covers or shades.

Table lamps must be located close to working areas. Their illumination must be such that the occupants can read and write without straining their eyes. Rheostats are used to regulate brightness.

During flights at night, especially under unfavorable weather conditions, the pilot may develop visual ("psychic") illusions, previously described when we were talking about flights under difficult meteorological conditions.

When the aircraft enters the beam of a searchlight, the pilot is blinded. On leaving the beam, observation of surrounding space and the instruments in the cabin is disrupted for some time. This period of time will increase the longer and more intensive is the exposure of the eyes to light, and the darker is the night. Therefore, when entering the beam of a searchlight, the pilot must take measures to protect himself against bright light (use a light filter or a shade, use the shadow in the cabin, make a maneuver to get out of the searchlight beam). On leaving the beam, the pilot must steer the aircraft /236
by instruments until his vision becomes accustomed to natural illumination, after which he may return to visual flight.

Deterioration of night vision and development of illusions on night flights are promoted by the following:

— abrupt transition from bright light to darkness and vice versa;

— excessive or insufficient illumination of the aircraft cabin; light reflections on the glass of the instruments and cabin;

— insufficient oxygen supply;

— repeated influence of radial accelerations, noise of high intensity, overcooling or overheating of the body;

— functional disorders of the vestibular apparatus;

— overfatigue, neuropsychic disturbances, lack of sleep, extreme physical stress;

— drinking alcohol on the night before and on the day of the flight, excessive smoking;

— overfilling the gastrointestinal tract, urinary bladder, altitude meteorism;

— a diseased condition, as well as the condition immediately following recovery from an illness;

— lack of vitamins A, C and vitamins of the B group in the diet.

Measures which are capable of improving the general state of the body and retention of normal night vision include the following:

— correct organization of the light conditions in the crew's quarters, at the airfield itself and in the aircraft cabin;

— maintenance of a correct program of work and rest;

— correct diet, adequate vitamin content in the diet and additional doses of vitamins;

— systematic performance of physical culture and sports;

— sufficient oxygen supply at all flight altitudes.

Vitamins A, C and vitamins of the B group have an important influence on visual processes in general, and on dark adaptation of the eyes in particular. The presence of a full complex of vitamins in the diet not only has a positive affect on visual functions, but also improves the general state of the pilot's body.

During night flights, the need of the body for vitamins increases. To cover the vitamin deficiency, additional vitamin administration is employed. This means that the flight crew is given a tablet before the flight which contains Vitamins A, B_1, B_2, B_6, P, PP and C. /237

Special attention must be paid to oxygen supplies. A shortage of oxygen affects all of the functions of the eye. On night flights, the oxygen supply must be switched on on the ground.

There must be constant medical supervision so as not to allow night flights to be made by individuals who do not satisfy the requirements as far as vision is concerned. These include individuals with reduced visual acuity (less than 0.8 in each eye), disturbed color vision, and dark adaptation.

CHAPTER IX

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DIET OF THE FLIGHT CREW

Physiological Significance of Food Substances

The basis of all life processes in the human organism is the constant exchange of substances between the organism and the ambient medium. During the working day, man expends a large amount of energy. Energy comes from food substances that are taken into the organism daily with food. Food substances include proteins, fats and carbohydrates. The diet must contain vitamins, inorganic substances (sodium chloride, calcium, potassium, phosphorus, iron), microelements, as well as water.

The human food ration makes up a combination of foods that consist of foodstuffs and water. The composition of the foodstuffs in the ration must be such that it supplies as completely as possible all of the physiological requirements of the organism. These requirements differ in various individuals; they depend on the nature of the activity, the state of the metabolism in the organism, the relationship between the processes of assimilation and dissimilation, as well as age, energy consumption in carrying out work, condition of the central nervous system and endocrine glands, as well as the conditions of the ambient medium. Thus, for example, under conditions of low temperature, strong wind, or high humidity of the air, the consumption of food substances in the organism increases.

The energy or food value of food depends on its chemical composition and is expressed in large calories. It is considered that 1 gram of protein or carbohydrates provides 4.1 kcal of heat, while 1 gram of fat provides 9.3 kcal.

Consequently, if we know the chemical composition of food, we can calculate its energy value. /239

The diet must be rational. The organism must periodically receive an amount of food such that it will be timely and correct for fulfilling all energy requirements and therefore will maintain the energy equilibrium of the organism. In organizing correct nutrition, it is also necessary to strictly maintain the content of the required vitamins and inorganic substances in the food.

Diverse and correctly prepared foods will satisfy the needs of man for the necessary food substances.

Proteins

Processes of dissimilation and assimilation are constantly going on in the organism; they involve the breakdown of certain protein substances and the formation of others, with constant renewal of cell substance. To balance these two processes, it is necessary that proteins be ingested daily into the organism. Protein in the human organism is formed only from protein (from its component parts, the amino acids) taken in with the food. It cannot be formed from other foodstuffs (fats, carbohydrates).

Proteins are the materials which make up all cells of the organism. They play an extremely important role in the regulation of exchange processes of the organism, and are especially necessary as a background for normal fat, carbohydrate, and vitamin metabolism. For example, with an insufficiency of protein, vitamins are poorly assimilated or not assimilated at all, even when there are enough of them in the food.

Approximately 15% of the energy expended by the body is provided by protein.

Shortage of proteins in the food ration is one of the principal reasons causing a drop in the ability of the organism to combat infectious diseases; a shortage of protein decreases the intensity of the hemopoiesis processes, disturbs the activity of the nervous system and endocrine glands and other vitally important functions. A prolonged shortage of protein may lead to irreversible disruption of the functions of individual organs.

However, an excess of protein is accompanied by the accumulation of its /240 incomplete oxidation products in the blood, which has an unfavorable effect on the functions of many organs and systems, especially the central nervous system.

According to data from the Institute of Nutrition of the Academy of Medical Sciences of the USSR, the daily ration of an adult human being, depending on the nature of his work, must contain from 102 to 154 grams of protein. The scientifically based daily norm for an adult human being is considered to be (on the average) 1.5 grams of protein per kilogram of body weight. This norm may change depending on age, sex, level of physical and mental stress, and climatic conditions.

For an approximate calculation of the amount of protein in the daily ration, we can use Table 23 (which shows the content of protein per 100 grams of product).

Biological origin of protein is of great importance for the nutrition of the organism. There are proteins of animal and plant origin. Proteins are broken down in the course of cooking into simpler chemical compounds — amino acids. The amino acids, which are absorbed through the walls of the /241 small intestine, pass into the blood. The body builds its own protein from the amino acids. During the course of metabolism, some amino acids may be

TABLE 23.

Product	Amount of protein, grams
Beef (Grade 1)	16.1
Pork	13.9
Meat of other animals and fowl	13-19
Fresh-water fish	13-17
Whole cow's milk	2.8
Cheese	20-22.6
Egg whites	10.6
Cottage cheese (curds) (20% fat content)	11.1
Cottage cheese (fat-free)	13.6
Whole-wheat bread (from Class 1 flour)	6.7
Rye bread	5
Soy beans	28.1
Kidney beans	19.2
Peas	19.3
Groats	6.4-11
Sweet almonds	10.6
Walnuts	6.8
Peanuts	17.4

changed into others according to the needs of the organism. However, the body is unable to develop certain amino acids; they must be supplied with the food in ready form. These amino acids are called essential. Food in which sufficient amounts of essential amino acids are contained is full valued.

Animal proteins are more valuable than plant proteins, since they contain the right types and amounts of essential amino acids, especially those such as methionine, tryptophan and lysine. The food ration of adult human beings must contain no less than 50% protein of animal origin. Of these proteins, the most valuable are the proteins of dairy origin, since methionine is included in their composition. This regulates the activity of the liver, vitamin metabolism, and operation of certain endocrine glands, and prevents the development of atherosclerosis. However, proteins of plant origin are also a good source of essential amino acids and form the best combinations with animal proteins.

Fats

Fats contain almost twice as many calories as proteins and carbohydrates, and are the principal source of energy.

Fat which enters with food and is not used in the vital processes is stored in the cells beneath the skin, as well as the loose connective tissue surrounding the internal organs. Both subcutaneous and internal fat are sources of energy reserves and are used by the body during increased physical work. This fat has been called reserve or stored fat. The volume of stored fat in the body changes: it decreases when heavy physical work is performed and during starvation or exhausting diseases, and increases as a result of insufficient activity and excessive intake of fats and carbohydrates.

However, the significance of fat is not limited only to its energy characteristics. Fat is necessary for carrying out various vitally important functions in the body. Being a poor conductor of heat, fat protects the body /242
against cooling. Due to the elasticity and flexibility of fat, it can protect the internal organs against shock, vibrations, and displacements. It makes up the protoplasm of the cells in the form of complex, relatively stable compounds with proteins. Fat in the organism may also be formed from carbohydrates and to some degree from proteins.

The biological composition of the fat employed is of great importance. In the course of cooking, fats break down into glycerin and fatty acids.

Among the fatty acids, an important role is also played by the so-called unsaturated fatty acids (linoleic, linoleneic, arachidonic). They have high biological activity, stimulate oxidation processes in the body and prevent the development of atherosclerosis. These acids are not synthesized in the body (practically speaking), and must constantly be taken in with the food.

Fish oil and plant fats are richest in unsaturated fatty acids (sunflower, corn, soya and olive oil). Such fats as lard, beef fat, mutton fat and margarine contain fewer unsaturated fatty acids, and are therefore less valuable.

Together with certain products in the diet, fats are sources of Vitamins A, D and E. Fats of animal origin are specially rich in Vitamins A and D (butter, fish oil). Plant fats contain Vitamin E. Fats are extremely necessary for obtaining Vitamins A, D and E, since they are fat-soluble and break up rapidly in aqueous solutions. The presence of fat in the gastrointestinal tract promotes improved assimilation of these vitamins.

In addition to unsaturated fatty acids and vitamins, fats in food contain biologically active substances or lipoids. The lipoids are fat-like substances of complex structure. They make up all tissues and cells in our body. There are particularly large amounts of them in the nerve tissue, especially the brain.

Among the lipoids, we have a group of substances called the phosphatides, the most important representative of which is lecithin. It regulates the excitation processes in the cerebral cortex, thereby playing an important role in higher nervous activity, and also prevents the development of atherosclerosis and liver disease. Lecithin is contained in large amounts in natural milk /243
(dairy) products. Fats promote the assimilation of proteins and limit their breakdown during eating. With a sufficient fat content in the food ration, the proteins are used up more economically.

The daily need of the individual for fats is established as a function of the type of work and the surrounding conditions. The physiological norm for fats varies from 105 to 150 grams, amounting to 30% of the entire daily caloric content of the food. Here we are considering fats in pure form (butter and vegetable oil, grease) and the fats which go to make up other food products (meat, fish, curds, milk, eggs). From 70 to 80% of the fats which are taken in by the body with food must contain readily assimilable and vitamin-rich animal fats, mainly butter. In a balanced diet, the normal amount of fat must correspond to the normal amount of proteins, i.e., for each kilogram of body weight 1.5 grams of fat are required. For persons doing mental labor and for the elderly, the norm is 1 gram of fat per kilogram of body weight.

Fats are assimilated most completely if the food ration (made up of fats, proteins and carbohydrates) is characterized by the ratio 1:1:4. Failure to observe this rule will disrupt the assimilation of food substances.

Persons of advanced age should limit the use of fats somewhat. Vegetable fats should outnumber animal fats in their food ration.

Carbohydrates

Carbohydrates, like fats, provide a source of energy for the body. In an ordinary mixed diet, carbohydrates provide about 60% of the daily caloric content. Carbohydrates in the form of sugars or more complex compounds (starch and cellulose) are contained primarily in food products of plant origin; there are few of them in animal products.

Entering the gastrointestinal tract, carbohydrates (sugars and starches) are broken down under the influence of digestive juices into simple sugar substances (glucose, fructose and galactose). These substances are readily /244
absorbed by the wall of the gastrointestinal tract and enter the blood, afterwards the liver. In the liver, glycogen is synthesized from the glucose — this is so-called animal starch. Then, however, the glycogen is converted into a phosphorus compound and then into glucose, which enters the blood. The blood carries the glucose to all the organs and tissues. The completeness of carbohydrate metabolism depends on the intensity of the oxidation processes in the organism. A significant portion of the carbohydrates is oxidized to form final products, water and carbohydrates. If there is an excess of carbohydrates in the organism, they are converted to fats and stored in the

subcutaneous fatty cells and around the internal organs. Food rich in carbohydrates improves the operation of muscles and the heart, and increases the productivity of mental labor.

A shortage of carbohydrates in the diet is the principal cause of formation and deposition of fats in the body. Carbohydrates, like fats, when not taken in with the diet in sufficient quantities, may be formed in the body from fats and proteins. But the proteins, as we have already said, can only be formed from food protein. With increased muscular work, a sufficient quantity of carbohydrates in the ration prevents the breakdown of fats and proteins. In the event of a shortage of carbohydrates, the fats are oxidized first, and then the proteins.

Among the carbohydrates, the most important energy sources are the complex compounds (polysaccharides), primarily starch. The polysaccharides are very widely distributed in nature: starch and cellulose are the reserve and supporting substances of plants. Starch is stored in the leaves of plants, seeds, tubers, and rhizomes.

Carbohydrates are contained primarily in products which are rich in starch and sugar (bread and rolls and pastry products, groats, macaroni products, potatoes, sugar and honey, as well as berries and fruits). The content of starch in groats is 70 to 80%; it is 40 to 50% in bread and 25% in potatoes.

Cellulose makes up most of the organic substance on Earth. Cellulose enters the human body in large amounts with plant products. The intestine /245 does not contain enzymes which break down cellulose, so that it is absorbed only slightly by the organism and has no significance as a source of energy. However, cellulose plays an important role in the digestive process. By mechanically stimulating the walls of the intestine, it activates peristalsis and thereby promotes movement of the food along the digestive canal.

It should be mentioned that simple sugar substances (monosaccharides) are very rapidly absorbed. Glucose, for example, is absorbed 5 to 10 minutes after entering the stomach. On the other hand, the process of starch breakdown to simple sugar substances and their absorption requires a much longer time. Therefore, for rapid satisfaction of energy requirements, it is necessary to give the body sugar, while for slower and more regular absorption of carbohydrates, products containing starch are used.

The average daily need of a healthy individual is 7 to 8 grams of carbohydrate per kilogram of body weight.

Vitamins

Vitamins help to form enzymes and participate in metabolic processes. Vitamins regulate the direction and rate of the biochemical processes most important for life, activate the protective reactions of the body when it is subjected to the action of disease microbes, radioactive radiation, various toxic substances and so on.

There are more than 30 known vitamins. Seventeen of them are most important for the human organism. Vitamins have conditionally been assigned letters of the Latin alphabet and have chemical names.

Vitamins may be divided into water and fat-soluble types, depending on how they are dissolved. Water-soluble vitamins include Vitamin C, vitamins of the B group, Vitamins PP, H_1 (paraaminobenzoic acid), choline and Vitamin P, while Vitamins A, D, E, K and F are fat-soluble.

Vitamin C (ascorbic acid) is contained in literally all of the tissues of the body. This indicates its importance for physiological processes. The largest amounts of this vitamin are found in the brain, adrenal glands, and heart muscle. When the body lacks sufficient Vitamin C, the permeability of /246 the vascular walls increases so that elements of the blood may pass out through these walls into the surrounding tissue.

As we have already said more than once, Vitamin C plays an extremely important role in metabolic processes. The reducing (deoxidizing) properties of this vitamin allow it to participate in oxidation-reduction processes. As a catalyst, it readily reduces the oxidized forms of enzymes. At the present time, the influence of Vitamin C on carbohydrate and protein metabolism has been definitely established.

The cells of the central nervous system are particularly sensitive to a shortage of Vitamin C. When this happens, the cells undergo complex biochemical changes which disrupt their structure. The functional changes that arise intensify the shortage of Vitamin C in the body.

Investigators feel that Vitamin C normalizes the physiological functions of the nervous system and creates conditions for its regulatory effect on the basic vital processes.

With a shortage of Vitamin C, there is a reduction in the resistance of the body to infectious diseases, working ability decreases, apathy and fatigue develop, and there is rapid onset of exhaustion.

Vitamin C is found primarily in the dog rose, black currant, horseradish, green onion, red and white cabbage, radish, tomato, dock, orange, lemon, mandarin and apple (Antonovka variety).

Vitamin B_1 (thiamine) has a powerful regulating action, primarily on metabolic processes. This vitamin plays an especially important role in carbohydrate metabolism. This vitamin also has an important influence on other forms of metabolism: protein, fat, water and mineral.

A shortage of Vitamin B_1 in the body will lead to disruption of metabolic processes; toxic products will accumulate in the organism, and various disorders will develop as a result. Usually an increase in fatigue and tiredness in the legs occurs at the beginning; there is a deterioration of the appetite, and the digestive system is upset. Then there is increased irritability, lack /247 of sleep, distraction and depression; the work of the cardiovascular system is disturbed; shortness of breath and pounding of the heart develop following physical exertion. With a severe shortage of Vitamin B_1, there is damage to the peripheral nerves, so that a loss of sensitivity and even paralysis of the extremities may develop.

Supplies of Vitamin B_1 are not formed in the body, and this means that it must be introduced daily with the food; with increased consumption, it may need to be given in the form of special preparations. Vitamin B_1 is contained in rye flour and coarsely ground wheat, in buckwheat and oat grains, meat, liver and kidneys. Bran, yeast and baking yeast are richest in this vitamin.

An adult human being must receive 2 to 3 milligrams of Vitamin B_1 each day. In general, however, this dose depends on the required nutrition, the intensity of metabolism, activity, stress and the nature of the work. The more intensive the mental and physical work, the more carbohydrates in the diet, the greater the need for Vitamin B_1.

Vitamin B_2 (riboflavin) makes up the enzymes which regulate the oxidation-reduction processes in the body. It enters the body together with the food, but a certain amount of it is synthesized by intestinal bacteria.

In the case of a shortage of Vitamin B_2, the metabolism in the body is disrupted (primarily carbohydrate and protein metabolism). There is a deterioration of the use of protein in the body. A high content of protein in the food increases the need of the body for this vitamin, while a low protein content has the opposite effect, reducing it. Recently, data have been obtained which indicate a positive influence of B_2 on the synthesis of fats and hemoglobin in the body.

Vitamin B_2 is necessary for the activity of the central nervous system and the sensitive nerve endings, since this is where the most intensive tissue respiration takes place. With a shortage of Vitamin B_2 in the diet, this intensity decreases, leading to a disruption of many functions in the body. This takes the form of a decrease in appetite, a drop in body weight, development of headaches, weakness, inflammatory processes of the mucous membranes of the eyes, lips and areas of skin near them. In addition, a shortage of /248 Vitamin B_2 leads to a drop in visual acuity and color sensitivity of the eye.

Dark adaptation takes place much more rapidly if Vitamin B_2 is administered together with Vitamin A.

Yeast, egg whites, milk, beef liver and kidneys, meat and fish are richest in Vitamin B_2. No supply of this vitamin exists in the body. In the event of increased neuro-psychic or physical stress, the need of the body for Vitamin B_2 increases.

Vitamin B_3 (pantothenic acid) primarily regulates the final stage of metabolism of proteins, fats, and carbohydrates. A shortage of this vitamin in the body is seen very rarely. It is contained in all food products, but beef liver and kidneys, egg yolks, yeast, meat, buckwheat, rye, wheat, red cabbage and potatoes are richest in it.

Vitamin B_6 (pyridoxine) participates in the metabolism of proteins and fats. It also promotes the formation of hemoglobin, and plays an important role in metabolic processes in the brain.

Vitamin B_6 is contained in many foodstuffs of animal and plant origin; it is found in particularly large amounts in egg yolk, fresh-water fish, animal liver, milk, yeast, fresh green peppers, carrots and wheat.

Vitamin B_9 (folic acid) participates in the synthesis of choline, certain amino acids and nucleic acids, and affects the formation of erythrocytes and thrombocytes. Data are available indicating that Vitamin B_9 prevents the development of atherosclerosis. This vitamin interacts in the organism with Vitamins C and B_{12}.

Vitamin B_9 is contained in spinach, cabbage, beans, beef liver, and chicken fat. The daily need for this vitamin is 2 to 5 milligrams.

Vitamin B_{12} (cyanocobalamin) participates primarily in the biochemical formation of elements of the blood and bone marrow. Insufficient amounts of this vitamin in the body lead to disruption of the hemopoietic process.

Vitamin B_{12} has an extremely favorable effect on the central nervous system. It has been established recently that this vitamin has a positive effect on the growth process of man and on the activity of the heart muscle.

Vitamin B_{12} is contained primarily in products of animal origin. It is found in particularly large amounts in animal and fish liver (sheatfish, pike, perch, cod) as well as caviar, while it is somewhat less plentiful in egg yolk, fresh meat and milk.

Vitamin B_{15} (pangamic acid, pangametin) is highly effective in pathological processes accompanying oxygen insufficiency in the tissues. It promotes the inactivation of various toxic products formed within the body and admitted from the external environment.

Vitamin PP (nicotinic acid), together with certain vitamins, makes up a complex enzyme system and participates in carbohydrates, protein, and other forms of metabolism.

Vitamin PP affects the functional state of the cardiovascular and central nervous systems.

A shortage of Vitamin PP in the body disrupts the activity of the central nervous system (leading to the development of fatigue, lack of sleep, deterioration of the memory, which, in turn, is the causes of functional disruptions involving other organs and systems. In addition, a lack of Vitamin PP may lead to the development of pellagra, a disease which is characterized by inflammatory processes on the skin, diarrhea, and a drop in the level of psychic activity. The cause of the disease is disruption of protein metabolism. The development of pellagra is promoted by a shortage of Vitamins A, C, B_1, B_2 and B_6 in the diet.

Vitamin PP is contained in various products, but it is found mostly in yeast, liver and kidneys, milk, and cereals (especially bran).

Vitamin H_1 (para-aminobenzoic acid, PABA) participates in the formation of skin pigment (tan) and hair, has a positive effect on the function of the reproductive glands, and prevents burns caused by ultraviolet rays. A systematic insufficiency of this acid is indicated first of all by a loss of hair. Sources include yeast, sprouts from grain or cereal plants, liver and mushrooms.

Choline promotes the excretion of fat frcm the liver and cholesterol from /250 the body, and serves as a structural material for lecithin. In case of prolonged lack of choline in the diet and a limited utilization of protein, severe disruptions of the function of the liver (cirrhosis) may develop.

Choline is contained in egg yolk, brain tissue, fresh milk and sprouts from grains of cereal plants.

Vitamin P (rutin) increases the strength of the capillaries (reduces their permeability), preventing the formation of subcutaneous hemorrhages in radiation disease, has a favorable effect on the healing process in wounds and frost bite, stimulates the formation of certain elements of the blood, and also protects Vitamin C against oxidation.

Vitamin P is contained in lemons, oranges, mandarins, dog rose, black currant, tea and pepper.

Vitamin A (axerophthol) stimulates the growth and multiplication of cells and also maintains the normal condition of the cutaneous coverings and mucous membranes. In addition, Vitamin A is necessary for normal functioning of the reproductive apparatus and the organs of vision (the vitamin is contained in the optical purpura.

With a shortage or absence of Vitamin A, there may be keratosis of the epithelium, dryness of the skin and mucous membranes, a decrease in the total resistance of the body to infection, and such diseases as xeroophthalmia and hemeralopia ("night blindness") may also develop. In xerophtalmia, the retina of the eye is irritated, which in serious cases can lead to a loss of sight. In hemeralopia there is a sharp deterioration of night (dusk) vision.

Vitamin A is contained only in animal food. In products of plant origin, there are so-called carotenes, which are converted to Vitamin A when taken into the body. This vitamin may be stored in the liver. The substances richest in Vitamin A are fish oil, liver, butter, while carrot, squash, lettuce, green peas, apricots, peaches, whortleberries, currants and dog rose are rich in carotene.

The daily ration of the human being must contain about 1-1/2 milligrams of Vitamin A or 3.5 milligrams of carotene.

For members of the flight crew, whose work involves considerable visual stress, the need for Vitamin A exceeds the indicated daily dose. /251

Vitamin D (calciferol) stimulates the growth of the body, regulates the carbohydrate and phosphorus-calcium metabolism and metabolism of magnesium and iron, and also promotes an increase in the supply of glycogen in the liver and muscles. In children with a lack of Vitamin D in the diet, phosphorus-calcium metabolism is disrupted, and a serious disease called rickets develops as a result.

Vitamin D is contained only in products of animal origin, especially the liver of animals and certain fish.

Vitamin E (tocopherol) regulates the function of reproduction, has an influence on the protein, carbohydrate and fat metabolism, and participates in the synthesis of the nuclear substances of the cells. With a shortage of this vitamin in the body, there is a disruption of the reproductive function, as well as dystrophic changes in the muscles.

Vitamin E is found in plant oils and cereal sprouts.

Vitamin K (vicasol) stimulates the development of prothrombin in the liver, and, consequently, effects coagulation of the blood. It also participates in oxidation processes in the body.

Vitamin K is contained in spinach, cabbage, lettuce and nettles.

Vitamin F (unsaturated fatty acids — linoleic, linolenic and arachidonic) has a significant effect on fat metabolism, and also activates the excretion of cholesterol from the body. With a shortage of this vitamin, eczema develops and the secretory function of the stomach is disrupted.

Vitamin F is contained in plant oils and fish oil.

The daily need of human beings for Vitamin F will be satisfied if the food ration contains 15 to 20 grams of vegetable oil.

The daily doses of vitamins required for a grown individual under ordinary normal conditions of vital activity are shown in Table 24.

A shortage of vitamins or disruption of vitamin metabolism in the body may develop as a result of a shortage of these substances in the food and a disruption in absorption in the gastrointestinal tract. Vital metabolism may be disrupted under prolonged conditions of oxygen insufficiency, as well as under conditions of very high or very low temperature of the surrounding air and with high physical stress.

TABLE 24.

Vitamin	C	B_1	B_2	B_3	B_6	B_9	B_{12}	B_{15}
Daily dose, mg	70—120	2—3	2.5—3.5	5—10	2—4	2—5	0.1—0.2	150
Vitamin	PP	H_1	choline	P	A	D	E	K
Daily dose, mg	20—25	2—2.5	2—4	50	1.5	0.3	5—50	15

With oxygen insufficiency, there is a decrease in the activity of respiratory enzymes; this becomes more noticeable as the partial pressure of oxygen decreases and the time spent at high altitudes increases. As a result, a shortage of vitamins in groups B, A, C, P and PP appears in the body.

As we have already mentioned more than once, in order to avoid these problems, and therefore to increase the resistance of the body to oxygen insufficiency, it is necessary before making an ascent to have additional complexes of vitamins. Thus, for example, it was found that under conditions of oxygen insufficiency and increased physical stress, in order to cover the needs of the body for vitamins, it was necessary to increase the daily intake of Vitamins A, C, B_1, B_6, P and PP by a factor of 5.

With high air temperature (25-50°C) and performance of moderate and heavy physical labor, it might be recommended to have the daily dose of vitamins given in Table 25. /253

TABLE 25.

Vitamin	A	B_1	B_2	C	PP
Daily dose, mg	2—3	5—7	4—5	100—150	30

At low air temperatures (working under polar conditions, as well as in other areas with a harsh climate) it might be recommended to have the daily dose of vitamins indicated in Table 26.

TABLE 26.

Vitamin	A	B_1	B_2	C	PP
Daily dose, mg	3	5	5	150	30—40

Since many vitamins are not stored in the body (excess amounts are excreted), unfavorable effects due to taking vitamins are very rarely seen. Cases are known in medical practice of serious problems in the body that arose as a result of taking vitamin preparations in amounts which exceeded the daily dose by hundreds of times. Thus, for example, when a large dose of Vitamin B_1 is taken (hundreds of milligrams a day), brief intoxication is observed, characterized by agitation, insomnia, speeding up of the pulse, dizziness, headache, and spasms in serious cases.

In the case of large doses of concentrates of Vitamin A, (one million IU or more) severe intoxication develps, accompanied by severe headache, fatigue, nausea, reddening of the mucous membranes and skin.

In the case of children who have taken a dose of Vitamin D a hundred times greater than the recommended dose, there is a sharp drop in appetite, headache, agitation, fatigue, nausea, diarrhea and spasms.

Unfavorable consequences may follow daily excessive use of liver from marine fish and animal liver, since this organ contains a large amount of vitamins.

It should be emphasized in particular that vitamins interact not only with one another, but with other food substances. It is also known that vitamins make up enzyme systems which have a powerful biological effect as catalysts in a complicated and continuous cycle of metabolism in the body. The lack or insufficiency in the body of one of the vitamins leads to exclusion of one of the links in this cycle and breaks up the course of metabolic processes in other branches. Therefore, it is necessary to use vitamin complexes in the diet and to determine correctly the quantitative content of /254 various vitamins in it, depending on the nature of the work and the conditions of the surrounding medium. Unjustified inclusion in the diet of a large dose of one or several vitamins may lead to unfavorable consequences.

Mineral Substances and Water

Mineral substances. Some of these make up the protoplasm of all the cells of the body, while others circulate in the body to regulate and reinforce various chemical processes. Mineral substances provide the necessary level of osmotic pressure in the tissues and biological fluids and participate with the proteins in maintaining a constant level of active reaction of the medium. Certain mineral substances promote normal functioning of organs and tissues.

The most important role in the body is played by sodium, potassium, calcium, magnesium, iron, chlorine, phosphorus and sulfur. Of these, the first four have a positive effect on the activity of the central nervous system, heart, and skeletal musculature. Calcium is the principal component in bone tissue.

Potassium is contained in large amounts in dried apricots, raisins, cabbage, potatoes and dog rose; calcium is found in milk, cheese, egg yolks and certain vegetables; magnesium is found in black bread, bran, buckwheat, groats, carrots and vegetables.

Iron is found in organic and inorganic compounds. It is in hemoglobin and myoglobin, and plays an important role in hemopeisis and oxidation processes. Iron is contained in large amounts in egg yolk, liver, meat, coarsely ground wheat flour, curds, fruit and spinach.

Chlorine is contained in the body primarily in the form of compounds with sodium and to a lesser degree with calcium. It has an effect on the activity of nerve cells and participates in digestion because it is a component part of the hydrochloric acid in the gastric juice. /255

Phosphorus and its compounds are especially important as far as the activity of the central nervous system is concerned. Phosphorus is found in large amounts in brain, liver, cheese, egg yolk, fish, meat and buckwheat groats.

Sulfur is a necessary component of the amino acids that make up many proteins.

The daily need of the organism of an adult human being for mineral substances is outlined in Figure 27.

TABLE 27.

Substance	Sodium	Potassium	Calcium	Magnesium	Iron	Chlorine	Phosphorus
Daily requirement, grams	4-6	2-5	0.8-1.0	0.3-0.5	0.015-0.02	4-6	1.5-2

On a normal diet the body receives the necessary amount of mineral salts. Only sodium chloride (cooking salt) usually is eaten in an amount which is much greater than the physiological need. Thus, for example, on the average a human being will eat this salt in the amount of about 15 grams a day, with a physiological need for only 4 to 6 grams. This is due to the fact that salt is used for giving food a pleasant taste.

An important biological role in the nourishment of man is played by microelements: cobalt, copper, zinc, iodine, fluorine, arsenic, bromine, etc. They play the role of biocatalysts, going to make up enzymes, hormones, and vitamins.

Water is a necessary component of living protoplasm. It is the solvent for most chemical substances in the body.

The body of an adult human being contains about 67% water (relative to the total weight). The amount of water in different tissues and organs is different. Thus, for example, blood plasma contains about 92% water, muscle tissue contains up to 76%, the gray matter of the brain contains 84%, the white matter of the brain contains 70%, fatty tissue contains up to 30%, and /256
bone tissue — from 16 to 46%.

A decrease in water in the body by 10 to 11% is accompanied by serious general disturbances, and if the water loss reaches 20 to 30%, the body will die. We know that with complete starvation but with drinking allowed, a human being can survive from 40-45 days and even longer, but he will die in 4 to 5 days if completely deprived of water.

Under ordinary conditions, an adult human being each day requires about 40 grams of water per kilogram of weight. Thus, for example, a 70-kilogram man requires 2-1/2 to 3 liters of water. This consists of about 1-1/2 liters of free liquid (tea, milk, soup, compote, etc.), about 1 liter of water contained in the food itself, and a certain amount of fluid which is formed in the tissues during oxidation of food substances.

Water exchange is closely related to the metabolism of other substances, especially that of minerals.

Assimilation of Food Substances and General Hygienic Requirements

Food substances taken into the body are assimilated and used incompletely. The degree of utilization of proteins, fats, carbohydrates, vitamins, and mineral substances depends on the intensity of the digestive process, the intake of the products of food breakdown to the blood, as well as the quality of the food. Butter is assimilated best of all the fats, while pork fat is assimilated less well and beef and mutton fat are worst of all. Animal proteins are assimilated well: meat, fish, milk, eggs. Vegetable proteins in bread, groats, peas and beans are assimilated less readily.

An important influence on the assimilation of food substances is exerted by their proportion in the ration. Thus, for example, a shortage of protein in the diet will reduce the assimilation of other food substances; a shortage of fats will also have a negative effect on the assimilation of food by the body.

An important condition for good assimilation of food is appetite. Cleanliness in the dining room, a polite and cheerful mood, an attractive setting of the table, pleasant arrangement and smell of tastefully prepared dishes will increase the appetite and, consequently, the secretion of juices.

One of the most important requirements for the diet is the temperature. /257 It must not be above 55°C. In the case of liquid dishes and drinks, the most pleasant temperature is about 50°C, while in the case of those in the form of a paste, it is 40-45°C.

Details of Diet for Flight Crews

It has been established that under the influence of physical factors of flight and high neuroemotional stress, a pilot's body may undergo considerable changes in the physiological functions accompanied by disruption of working ability. In conjunction with flying activity, there is an intensification of all forms of metabolism. With oxygen insufficiency, in addition, there is inhibition of the digestive glands and the motor function of the digestive organs.

It is therefore very important to have correct organization of the nourishment of the flight crew. Strict performance of a scientifically developed method of feeding promotes retention of the health of the pilots, increasing their resistance and stability with regard to the effect of unfavorable factors of the ambient medium.

Caloric Content and Food Composition

All measures involving the organization of efficient preflight and postflight nourishment must increase the working ability of the flight crew.

The most important aspects of the nourishment of a flight crew are caloric content and composition of the food.

The food must be of good quality and must supply the body of the pilot with all necessary substances for normal metabolism; it must also provide for his energy consumption.

The average daily energy consumption of a pilot is about 4000 kcal. However, the total energy supply in the daily ration of a pilot is 4617 kcal, in which proteins make up 134, fats 164, and carbohydrates 620 grams. The ration of the flight crew of a jet aircraft has a caloric content of 4889 kcal, and the products contained in this ration contain 140 gm protein, 173 gm fat, and 660 gm carbohydrates. The daily ration also contains the necessary amount of vitamins, mineral substances, and microelements.

In daily nutrition, the total caloric content of the ration is made up of /258
13% proteins, 32% fats, and about 55% carbohydrates. Hence, the nutrient value of the products in the flight ration fully corresponds to the physiological

means of the pilot's body and makes it possible to meet its energy consumption completely.

Preflight Nourishment

By preflight, we mean the food eaten during the 24 hours preceding the flight.

One of the most important aspects of the food hygiene of the flight crew is the necessary intake of food 1-1/2 to 2 hours before takeoff. Practice and research have shown that when this rule is observed the resistance to shortage of oxygen, drops in barometric pressure, acceleration, as well as working ability of the pilot are increased considerably. This is explained by the fact that about 1-1/2 to 2 hours following intake of food, at the height of digestion, the very necessary nutrient and tonic substances are entering the blood; they are vital to the activity of the body under stress and stimulate the activity of the nervous and cardiovascular systems.

The preflight diet must be small in volume and weight and consist of readily digestible and easily assimilated high-caloric products.

Following excessive eating, a feeling of heaviness develops in the region of the stomach, there is a reduction in the vital capacity of the lungs and respiration is impeded. Overfilling of the stomach may result in gastric pain during flight. These pains may be very severe, especially at overloads. In some cases, vomiting may result which is especially dangerous if a pressurized oxygen mask is being worn.

When flying on an empty stomach, there is a sharp decrease in the sugar content in the blood, as a result of which working ability may be reduced. In addition, there will be deterioration of the condition which may even lead to loss of consciousness. Therefore, flights on an empty stomach are categorically forbidden.

In the organization of preflight feeding, special attention must be paid to the ratio of contents of fats, proteins, and carbohydrates in the ration, considering their effect on the resistance of the organism to unfavorable flight factors. For this purpose, it is recommended that the daily preflight ration be made up so that the amount of carbohydrates is 60-65% and proteins make up 10 to 15% (fats 20-25%) of the total caloric content. /259

Studies conducted in barochambers and in flight have shown that a shortage of fats and proteins in the diet reduces the resistance of the body to high altitudes.

In making up the preflight ration, it is necessary to consider the nature of the flight and put together a special menu.

On the night before and on the day of the flight, it is recommended the menu include dishes which are rich in easily assimilated carbohydrates and chemically stimulating to the digestive glands and have a minimum cellulose content. Such dishes, for example, include the following: strong meat broth with dumplings, vegetable broth, rice soup, soup with macaroni or vermicelli in meat broth, dried herring, steak with potatoes, liver cooked with potatoes, fried brains, chicken, nonfat fish, macaroni or vermicelli baked with egg yolks and ground cheese, cheese pancakes, puddings, jelly made from fresh berries and fruit, mousse, pastry, biscuits, sugar, marmalade, chocolate, coffee, tea, etc. In order to give a better taste and smell, it is necessary to add onion, garlic, horseradish, mustard, pepper, vinegar, dill, parsley, etc. These flavoring substances are good stimulators of the initial flow of juices and the digestive process as a whole. However, these flavoring substances must be added in moderate amounts, since too much can cause deterioration of the digestion. It is not recommended that fatty meat or fowl be included in the preflight diet, since fat inhibits the activity of the digestive glands and slows down the movement of the food from the stomach into the intestine.

It is categorically forbidden to use alcoholic beverages on the night before or just before takeoff. They sharply reduce the working ability and general state of the organism.

The diet must also contain a sufficient amount of all the vitamins. As we have already said, during flight activity, the need of the body for vitamins increases considerably. Therefore, in order to make up for vitamin deficiency (regardless of the value of the pilot's ration as far as content of basic food substances is concerned), it is necessary to use additional vitamin complexes. To do this, it is recommended to use the doses of vitamins listed in Table 28.

TABLE 28. /260

Vitamin	C	P	A	B_1	B_2	B_3	B_6	PP	E
Dose, mg	100—200	100	2	3—4	3—4	20	4	30	50

The dose of Vitamins B_9 and B_{12} depends on the nature of the flight, primarily on its duration. In addition to vitamins, the daily flight ration of the pilot must contain 1.6 gm phosphorus, 1.0 gm calcium, 0.02 gm iron, 2-5 gm potassium and 0.5 gm magnesium.

In making up the preflight menu, it is recommended that several varieties of dishes be used on different days for breakfast, lunch and dinner; in this way, any one of them can correspond to the requirements of preflight feeding.

On the day of the flight, the use of products of vegetable origin is limited. On ordinary days, when there are no flights, this limitation is removed.

In organizing preflight nourishment, it is necessary to pay considerable attention to preventive measures aimed at cutting down gas formation in the intestine (altitude meteorism).

Gas formation in the intestine is a very important factor when using products in the diet which contain large amounts of plant cells. Therefore, the preflight menu must exclude peas, beans, kidney beans, lentils, millet, oatmeal and barley, as well as kvass and carbonated water. But fruits, berries and vegetables may also be given in the form of cream, jelly, kissel, juice and puree. Rye bread, as well as potatoes, cabbage and other vegetables (following suitable treatment in the kitchen) may be included in strictly limited amounts.

It is not permissible to replace individual products in the pilot's ration by others which might increase the content of plant cellulose in the diet.

To suppress the fermentation processes in the intestine and reduce gas formation, it is recommended that kefir, acidophylin, sour milk, as well as onions and garlic be eaten on the night before the flight.

Feeding Schedule

For sensible feeding of a flight crew, it is not only necessary to work out a scientifically based diet, but also to maintain a correct feeding schedule.

By feeding schedule, we mean the time at which food is taken during the day with observation of certain intervals between intake, as well as the amounts and quality of the distribution of the daily ration over the individual meals.

The feeding schedule must be strictly observed by the established order of the day. The food must be always taken at the time scheduled for it. In this case, thanks to a conditioned reflex mechanism, a certain rhythm of operation of the digestive apparatus is also established in the systems associated with it. Therefore, the activity of the digestive glands will begin at the right time, and the food will enter the stomach which is already prepared for its digestion. As a result, the process of digestion and assimilation of food substances will be improved. Disorderly intake of food disrupts the established rhythm of activity of the digestive system, the organs begin to operate inharmonically, the process of digestion itself will be disturbed and the assimilation of food substances will be reduced. All of this has an unfavorable effect on the vital activity and the working ability of the body, and may finally lead to gastrointestinal ulcers (gastritis), colitis and other diseases.

The number of meals taken per day and their scheduling is of great importance.

The most sensible way is to eat four times a day with intervals of 4 to 5 hours between meals. For rest at night, 9 to 10 hours are provided. This time is sufficient for the digestive glands to rest, protecting them from overstress. With such intervals between meals, a uniform load is placed on the digestive apparatus, so that the food is processed and assimilated better.

In the usual order of the day (i.e., when flights do not take place) breakfast must be eaten after getting up, and a snack is eaten three to four hours after breakfast; lunch comes about an hour after the end of work and dinner comes at 2 to 3 hours before going to bed. We know that the order of the day (the beginning of the flight) may change depending on the state of the weather and the problem of military preparedness. In this connection, it is necessary to change the distribution of the daily ration of the flight /262
crew. A rough distribution of the daily ration by meals (in % of total caloric content) depending on the order of the day is given in Table 29.

On routine night flights, it is recommended that breakfast be eaten at the end of the night flight, with a snack before going to bed and rest, lunch 4 hours after the snack, a first dinner 1-1/2 to 2 hours before the night flight and a second dinner in the interval between flights.

TABLE 29.

Meal	Non-flying day	Daytime flights			During day before night flight	Non-flying day in hot weather
		3–5 a.m.	8–9 a.m.	2–4 p.m.		
1st breakfast	20—25	10—15	20—25	20—25	20—25	20—25
2nd breakfast	15—10	25—20	15—10	15—10	—	15—10
Lunch	40—45	35—40	35—40	35—40	40—35	30—25
1st dinner	25—20	30—25	30—25	30—25	35—30	35—40
2nd dinner	—	—	—	—	15—10	—

We know that the processes of digestion slow down during the night. The excessive intake of protein in the dinner, and especially immediately before going to bed, leads to a disruption of sleep. Therefore, it is desirable to include in breakfast and lunch a large amount of products rich in protein (meat, fish) while vegetable and milk dishes should predominate at dinner. Consequently, dinner must be light and eaten 2 to 2-1/2 hours before going to bed.

Under conditions of a hot climate, as well as in the summertime in middle latitudes, the flight crew may experience a loss of appetite and loss of body weight as well. Under such conditions, to normalize the nourishment, a daily distribution of meals is recommended. An example of the distribution of the ration on a day on which no flights take place in this case is indicated in Table 29.

In hot weather, the menu should include cold dishes, salads, pastries, snacks, fresh fruits and vegetables, all of which excite the appetite and stimulate the operation of the digestive glands.

As we have already mentioned, at high air temperatures there is a considerable increase in the need of the body as far as vitamins are concerned.

It is therefore necessary to use additional vitamin complexes in the food eaten by the crew, especially Vitamins C, PP and the B group.

Correct nutrition also depends on the behavior and condition of the individual during the meal. The intake of food must take place in a quiet and comfortable atmosphere. At this time, all attention is concentrated on the act of eating, and it is necessary not to hurry but to chew the food carefully. Hastily eaten food is digested less readily and assimilated poorly. Practice indicates that a flight crew should have 30 minutes each for breakfast and lunch, and 45 minutes for dinner.

Under any conditions of activity of the flight crew, it is necessary to add observations on the correct mode of eating. It is desirable that the flight crew dine in a separate dining room, located near the airfield. When necessary, the food must be prepared directly at the airfield.

Aspects of Nutritional Hygiene at the Airfield

The food brought to the airfield should be prepared at stationary flight dining rooms. Prepared food must be transported in insulated containers. This may be accomplished with special portable dining rooms. The hot food should not be kept at the airfield for more than 1 hour. When necessary, it must be reheated before serving. Serving of the food must take place at the times established by the order of the day in accordance with the feeding schedule.

In organizing feeding at the airfield, it is necessary to carry out all sanitary and hygienic requirements strictly.

Feeding Aboard the Aircraft

During long flights, aircraft crews will need to eat on board (flight food packages), while observing the basic requirements for the schedule of preflight nourishment. In a flight lasting longer than 4 hours, each crew member gets one food pack for every four hours he is in the air.

The caloric content of the entire food pack is equal to about 890 kcal, containing 25 grams protein, 28 grams fat and 129 grams carbohydrate, as well as the required amount of vitamins and mineral substances. /264

The products in this pack must have high nutrient value, be readily assimilated and have a pleasant taste. In addition, they must contain very little cellular matter, must not cause thirst and be ready to use without additional cooking. The quality of these products must be strictly monitored.

For heating the food, it is desirable to have devices for electric heating aboard long-range aircraft. At the present time, preserved soups and purees (chicken, meat, vegetable) are widely used, as well as preserved meat, fruit and chocolate sauce, fruit and milk, cream, chocolate sauce, marmalade, natural fresh fruit and vegetable juices, hot tea flavored with fruit or berry extracts or citric acid, black coffee, etc.

It is very important on a long flight to maintain normal water and mineral metabolism, i.e., to observe a drinking schedule. If this is disturbed, the crew members will lose weight and become tired more easily. To avoid this, the aircraft should carry sufficient drinking water and beverages.

To increase the mental and muscular working ability, improve the processes of visual perception, and retain the level of alertness during a long flight, all crew members are recommended to take vitamin preparations every three to four hours (vitamin pills containing Vitamins C, P and the B group).

The products in the flight crew meals are packed in several meals and in several packaging varieties for diversity of the meals. They are arranged for uniform intake in bags. The number of bags depends on the duration of the flight.

In the flight bags, in addition to the meals, there must also be tools for opening tins, individual tableware, tubes for drinking and paper napkins. /265

The flight bags, as well as thermos bottles with tea, coffee and water are loaded prior to takeoff at the airport and entrusted to the individual responsible for feeding the crew during the flight. Aboard the aircraft, the flight bags and thermos bottles are placed in the locations provided for them.

It is recommended that the first meal aboard the aircraft be eaten about 3 hours after takeoff, and then every 4 hours of the flight thereafter. The crew members take turns in eating the food as authorized by the commander of the crew.

Before each meal, it is necessary to check the quality of the products (appearance, smell and taste). In the event of the slightest doubt regarding suitability, a product should be omitted from the ration. It is categorically forbidden to use leftovers from tins that were opened earlier.

We know that in high-altitude flights each member of the crew will need to use the oxygen system and not take off his oxygen mask. This complicates eating. In order to simplify the process, liquid and semiliquid foods are provided in special packs. It is then necessary to follow strictly the rules for eating.

During high-altitude flights, when the rarefaction in the pressurized chamber will equal the rarefaction at an altitude of 5,000 m, it will be necessary to turn on the continuous oxygen feed before eating and to loosen the fastenings of the oxygen mask some 2-3 centimeters. Then the mask can be rapidly removed and simultaneously pulled away from the face. Each time, as soon as the food has been placed in the mouth, the mask is put back in the original position and held in place against the face while chewing. After the meal is over, the mask must be returned to the normal position, the fastenings tightened, and the continuous oxygen feed shut off.

If the fastening of the mask is loosened during the flight due to some conditions that arise or because of the nature of the oxygen respiratory apparatus and the mask cannot be removed (flight at altitudes above 12,000 m, when the cabin pressure is below the pressure at an altitude of 5,000 m), intake of food takes place through a special mouthpiece (tube), for which a separate valve is provided in the oxygen mask. In this case, special liquid or semiliquid foods, stored in special tubes, are used.

It is desirable that the individual who is eating be observed at this time by some other crew member who is using normal oxygen supply at this time, so that he can render assistance if there should be a problem. /266

In the event of sudden decompression of the cabin, eating must cease at once; the normal oxygen supply must be restored and the pressurized mask applied to the face.

The entire flight crew on a long-range flight must be taught in advance the technique of taking food in flight.

Emergency Food Supply

In addition to the food pack intended for eating on a long flight, each crew member is supplied with an emergency food supply to be used in the event of a forced landing or leaving the aircraft in a sparsely populated area. This food supply is packed in special boxes (bags) and stored aboard the aircraft. It may also be located in a special pocket on the pilot's suit or together with the parachute on the back of the seat.

The emergency food supply contains high-calorie products (chocolate, sugar, pastry, cakes, candies, etc.) which may be stored for a comparatively long time under appropriate conditions. It is necessary to check the quality of these products periodically.

In making flights in hot climates or over the sea, the crew must have a supply of good quality drinking water as well.

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